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Control of Air Emissions from Process Operations in the Rock Crushing Industry

JACA Corp, Fort Washington, PA

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Fort Washington, PA 19034

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CONTROL OF AIR EMISSIONS FROM PROCESS OPERATIONS IN THE ROCK CRUSHING INDUSTRY

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CONTROL OF AIR EMISSIONS FROM PROCESS OPERATIONS IN THE ROCK CRUSHING INDUSTRY

by

JACA Corp.
550 Pinetown Road
Fort Washington, PA 19034

EPA Project Officer: Norman Edminsten
Region X
Enforcement Division

Contract No. 68-01-4135
Task No. 19

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Washington, DC 20460

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ABSTRACT

Three basic methods of controlling emission from process operations in crushed stone plants are described - dry captive systems using fabric filters, wet suppression systems and combinations of these. Operational problems with these systems associated with plant portability and product size are discussed. Examples of good design practices and maintenance procedures for these control options are covered. An electrostatic charged fog technique for control of small dust particles is described and operational problems listed. A second part analyzes the downwind effects of reducing emissions for worker safety.

This report was furnished to the U.S. Environmental Protection Agency by JACA Corp., Fort Washington, Pennsylvania, in partial fulfillment of Contract No. 68-01-4135, Task No. 19. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency.

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SUMMARY

The basic operationally proved methods of controlling dust emissions are: (1) suppression of the dust by the application of wet sprays preferably with a surface active ingredient to reduce water surface tension and (2) the use of hoods, ductwork and fabric filters in a dry capture system. It is not unusual to find a combination suppression and capture system with emissions from the early parts of the process (larger size stone) controlled by suppression and later process points (smaller size stone) controlled by captive means.

Performance of either of these systems degrades appreciably when appropriate maintenance procedures are not followed. Operation and maintenance practices are simple and inexpensive to follow.

Portable plants that are moved frequently encounter take-down and set-up delays and added costs due to configuration induced difficulties of connecting ductwork to the appropriate emission sources. These difficulties are not insurmountable.

Water costs for wet suppression systems or combination dry (captive) and wet suppression systems in arid regions add to production costs. These incremental costs viewed in the industry economic context should not preclude use of wet techniques however.

A new potential method of controlling fine particles less than 10 microns by an electrostatically charged fog is now emerging from the experimental stage. Important operational and economic factors must be resolved before the system will find widespread usage in stone crushing operations.

Efforts to control emissions from stone crushing plants benefit both the worker who is in proximity to the equipment and the residents of the surrounding area. Efforts of a company (except for receptor control) to meet either the MSHA or EPA standards are mutually helpful.

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TASK PURPOSE

Under Task 19 of Contract 68-01-4135 the Contractor was to describe control systems commonly used on stone crushing plants to control process fugitive dust. Typical annualized costs and maintenance procedures were to be noted. Special problems in the control of portable plants in arid regions were to be addressed.

In addition, the Contractor was to examine the possible amelioration of downwind ambient particulate contributions from plant operations resulting from process control designed to meet MESA (now Mine Safety and Health Administration) requirements.

This report is divided into two sections: Section I, Air Pollution Control of Process Operations, and Section II, Effects of MESA Control Strategies on Downwind Ambient Conditions.

INTRODUCTION

Industry Background

In evaluating information on control of air pollution resulting from crushed stone operations it is desirable to have a general concept of the industry. This includes plant distribution, size, concentration, raw materials, customers, and market economics.

The crushed stone industry is one of the largest mining industries in the United States with production in 1975 totaling 902 million tons, valued at $2 billion. Crushed stone sites are found in every state except Delaware. There were, according to the Bureau of Mines,[1] 5,523 operating plant sites in the United States in 1975. The plant site count by state is shown in Table 1. The production and market for this crushed stone is all within the United States. Export trade and foreign imports are negligible.

The raw materials used in the crushed stone industry are derived from all three geological classes of rock: igneous, sedimentary and metamorphic. The specific stone used is basically a function of its availability, quality and ability to meet the specifications and standards for a specific product. Some stone types are not well suited to the crushed stone market requirements. Shale, shaley limestone and slate are examples of stone whose chemical and physical properties are undesirable. On the other hand, the properties of limestone allow it to be used for a variety of end products. Because of its versatility and availability, about 70% of all stone crushed in the U.S. is limestone. Other stone types used extensively

Table 1

CRUSHED STONE PLANT SITES BY STATES*

State	Crushed Stone
Alabama	54
Alaska	116
Arizona	43
Arkansas	93
California	517
Colorado	81
Connecticut	18
Delaware	-
Florida	122
Georgia	74
Hawaii	34
Idaho	69
Illinois	325
Indiana	130
Iowa	337
Kansas	196
Kentucky	111
Louisiana	20
Maine	17
Maryland	31
Massachusetts	34
Michigan	49
Minnesota	102
Mississippi	8
Missouri	274
Montana	74
Nebraska	27
Nevada	96
New Hampshire	38
New Jersey	32
New Mexico	41
New York	92
North Carolina	92
North Dakota	5
Ohio	159
Oklahoma	76
Oregon	420
Pennsylvania	216
Rhode Island	4
South Carolina	34
South Dakota	21
Tennessee	135
Texas	206
Utah	26
Vermont	46
Virginia	128
Washington	254
West Virginia	52
Wisconsin	369
Wyoming	25
Total	5,523

*Source, Reference 1.

for crushing are: granite, traprock, argillite, diabase, sandstone, marble, quartzite, quartz and gneiss.

The largest market for crushed stone is the construction industry. Contruction use accounts for about 85% of crushed stone production which includes: dense-graded road base, concrete aggregate, bituminous aggregate, cement, and riprap. Other major crushed stone products are: lime, agricultural lime, mineral fillers, filter stone, glass, refractory stone and chemical stone.

Portable plants are often used by producers to solve a number of production and market problems. In situations where the demand for stone from a particular quarry does not justify the capital expenditure required for a permanent plant, a portable unit can be used to serve a cluster of quarries. This is often the case in the midwest and western areas where portable plants are used to build up stockpiles of crushed products, after which the plant is moved to the next quarry owned by the producer. It is difficult to pin down the number of portable plants. The Bureau of Mines reports activities at plant sites, a number of which could be served by a single portable plant. About 28% of the reported plant sites are worked by portable plant equipment, according to Bureau of Mines figures[2]. Portable plant sites by leading states in descending order of number of sites are: Iowa, Wisconsin, Illinois, and Oregon.

The wide distribution of crushed stone operations is due in part to the high costs of transportation relative to the cost of the product. The cost of transportation of crushed stone by water is significantly less than that for rail or truck, and where producer and user are close to water transport, the market sphere is enlarged.

Plant operations can range from a production capability of about 100 tons/hr. to over 1,000 tons per hour with annual production ranging from less than 100,000 tons to over 2 million tons. Bureau of Mines data[1] for 1973 (see Table 2) show that about 40% of the production is from plant sites of 900,000 tons and over annually, which account for only 10% of the total number of plant sites. Those with an annual production of less than 100,000 tons accounted for 23% of the total number, yet only 4% of the total production. This seemingly high concentration ratio is exaggerated by the fact that several plant sites are serviced by one portable plant. The crushed stone industry, nevertheless, illustrates a high concentration ratio with plant sites producing 1 million tons or greater, exerting a pronounced effect on total production.

The crushed stone industry competitive posture can be characterized[3] by the following:

1) Production is concentrated close to urban areas
2) Within a marketing region, yard prices are competitive
3) On public bids delivered price is competitive
4) Transportation costs are the dominant cost feature in competition
5) Product demand is essentially inelastic
6) Competition is basically intra industry; some inter industry competition exists where crushed stone may be substituted for sand and gravel.

Table 2

DISTRIBUTION OF ROCK CRUSHING PLANT SITES BY SIZE*

Plant Size thousand tons per year	No. of Plants in size range	% of Total	Contribution to National Production, % of Total
50-99	989	23	4
100-199	1,075	25	9
200-299	516	12	7
300-399	387	9	8
400-499	301	7	8
500-599	215	5	7
600-699	172	4	6
700-799	129	3	6
800-899	86	2	4
over 900	430	10	41
		100	100

*Source of Data, U.S. Bureau of Mines 1973 Statistics.

The inelasticity of overall industry demand, the concentration of quarries and plant sites near urban areas, and the high cost of product transportation results in a localized competitive picture, although competitive spheres of operation can be large in instances where the quarry (or pit) and customer are located near a rail or barge loading facility and/or if the quarry (or pit) produces unusual sizes or quality of material.

Sources of Air Pollution

Rock crushing activities can be broadly classified as quarrying and beneficiation. Quarrying consists of removal of overburden, the earth over the desired stone deposit; drilling blast holes; blasting; transport to beneficiation facilities. Beneficiation or process facilities include crushing, screening for size, conveying and storage. The information on controls for rock crushing plants and the effect of MESA compliance on downwind ambient in this report cover the beneficiation portion of the activities only.

The beneficiation may take place using either wet or dry techniques at the various crushing or screening processes points. Some plants use dry processing in all product sizes except the "fines" production, where wet processing is often used. Where wet techniques are involved the air emissions are significantly reduced over those in dry process operations. In those instances where wet process points are involved, processing of the water effluent is needed to correct for total suspended solids (TSS) in the wash water. Stone quarries are under a zero discharge system requirement which requires recirculation of the water with appropriate settling

ponds and in some instances treatment by flocculating agents to increase sedimentation rate.

The plants considered in this report are dry processing plants although the raw stone may be in an initial wet condition.

Once the rock is broken into pieces which can be accommodated by the primary crusher, either directly from a well-controlled blast or by a combination of blast and drop ball, the fractured rock is trucked to the first or primary crusher, where it is dumped onto a scalping screen and feeder which scalps (or removes) the smaller pieces and overburden which do not require primary crushing, therefore reducing the load on the crusher and removing unusable material, freeing the crusher for its purpose of crushing only the larger rocks. The scalped material is conveyed to a separate spoils pile for disposal, while the crushed material is generally conveyed to a surge pile (temporary storage pile) for distribution to subsequent processing points.

Crushers utilize compression and impact to mechanically stress the rock beyond its breaking point. Some crushers rely almost solely on impact, whereas at the other end of the range compression is used. The more impact involved for a given stone, the more mechanical propulsion of particles and air turbulence tends to increase emissions.

Screens are located before each crusher. Screens agitate the particles as they proceed across the surface so that each particle has an opportunity to align its two smallest dimensions with the screen holes. This process of agitation frequently developed by an eccentric action produces airborne dust by mechanical and air turbulence forces.

Whenever a material is transferred into a bin or hopper, or from one conveyor to the other, or into a screen deck or crusher, air is induced and displaced. This action is largely responsible for the smaller particles becoming airborne.

Thus the process areas that must be controlled for fugitive dust in stone crushing beneficiation steps are:

- Crushing Operations
- Screening Operations
- Storage
- Transfer Points

The number, location, type, and size of crusher and screens vary from plant to palnt depending on many factors. These factors include type of stone, production rate, range of products, and process space available. Figures 1 and 2 taken from Reference 4 show typical plant operations at 300 and 600 tons per hour. These are the model plants costed for air pollution controls later in this section.

Figure 1

TYPICAL HARD ROCK STONE CRUSHING PLANT OPERATING AT 300 TONS PER HOUR

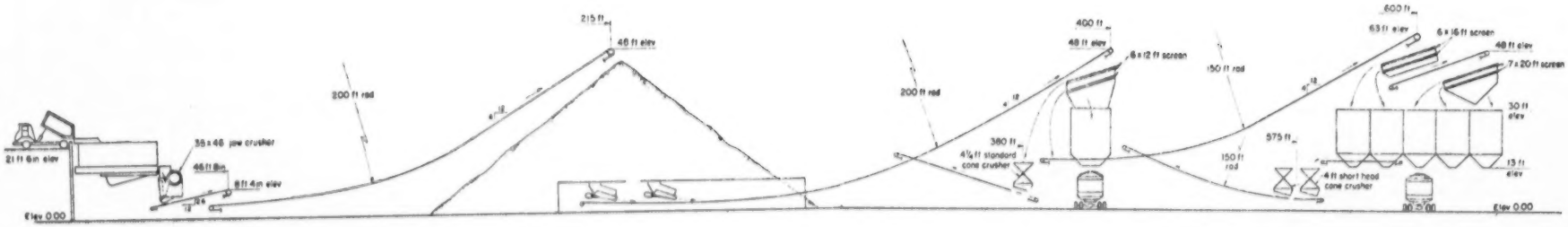
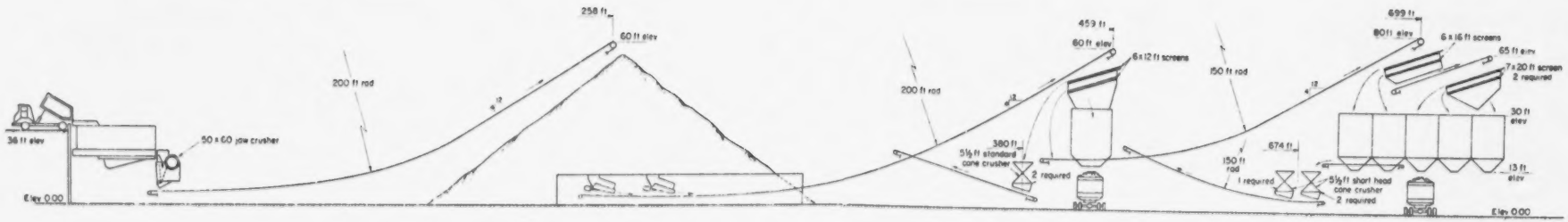


Figure 2

TYPICAL HARD ROCK STONE CRUSHING PLANT OPERATING AT 600 TONS PER HOUR



Section I

AIR POLLUTION CONTROL OF PROCESS OPERATIONS

Dust in the process operations of crushing, conveying, and sizing in crushed stone operations is generally controlled either by suppressing the tendency of the dust to become airborne by applying water that has been mixed with a suitable chemical to reduce its surface tension directly to the material, or by capturing dust that might otherwise become airborne in a closed dry collection system. The first will be referred to as wet suppression and the latter as a baghouse system. A recently introduced system using charged water sprays is emerging from the experimental phase but remains to be proven in field operations for crushed stone plants. All three of these systems will be described with emphasis on the first two since they have been successfully used in the field while the third is not fully demonstrated.

Crushed stone plants can be permanently placed with individual parts of the process nearly completely covered like those shown in Figures 3, 4, or 5; or they can be highly portable, mounted on truck beds, with a typical eight-day cycle from start of preparation for a move to completed erection of the plant at a new site (see Figure 6).

Unique application problems with portable plants are discussed at the end of each section on the two main control strategies covered in this report.

Figure 3
Permanent crushed stone plant with covered screen houses to the left. Plant is controlled by two baghouses, one left foreground, the second right background.
(Photo courtesy Pennsylvania Department of Environmental Resources, PennDER)

Figure 4
Distant view of plant producing crushed stone. All process units enclosed. Plant controlled by cyclone primary and baghouse.
(Photo courtesy of PennDER)

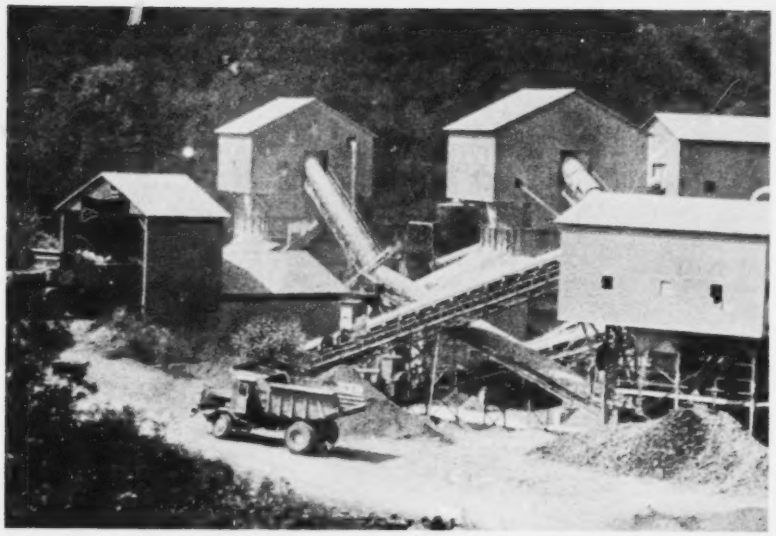


Figure 5

Close up of plant shown in Figure 4, emphasizing the covered, permanent type of plant operation.
(Photo courtesy of PennDER)

Figure 6

A Stone Crushing Plant Consisting of Unitized Portable Equipment
(Photo courtesy of Cedarapids, Iowa Manufacturing Company)

Wet Suppression System

The use of water as a means of dust suppression has been practiced for more than thirty years in both coal and non-coal mining operations. Water sprays, either directed by nozzles at transfer points, crusher exits and screening operations or applied manually by spray hose at muck piles (piles of rock from blasting) significantly reduce emissions.

System design is not guided by equations based on the physics of the situation, but rather on rules-of-thumb learned from many years of application experience. A wet suppression system as the name implies prevents or suppresses the tendency of the particles to become airborne. From the modest amount of water added (about 1/2 of 1% of weight of stone feed), it is obvious that an increase in density of a particle by means of retention of the water is not the sole mechanism for preventing emissions. The agglomeration of the small particles and the "sticking" of small particles to large pieces of stone is also involved. The precise mechanism of suppression is not as important as the fact that dust is suppressed when water is applied. As discussed later, water alone has poor wetting properties and a solution including a surfactant or surface active ingredient is usually applied. This substantially reduces (about 4:1) the amount of water that is required.

Application is made by spray heads mounted on a spray bar as in Figure 7. There are hundreds of different spray head designs when the combinations of flow, droplet size, coverage angle, spray crossections, etc. are considered. Droplets are generally formed by the water pressure on specially designed channels and exit orifices in the spray heads. Very small droplet sizes that rely on air atomization are practically never used. Different size and types of sprays are often used on different parts of the plant - the

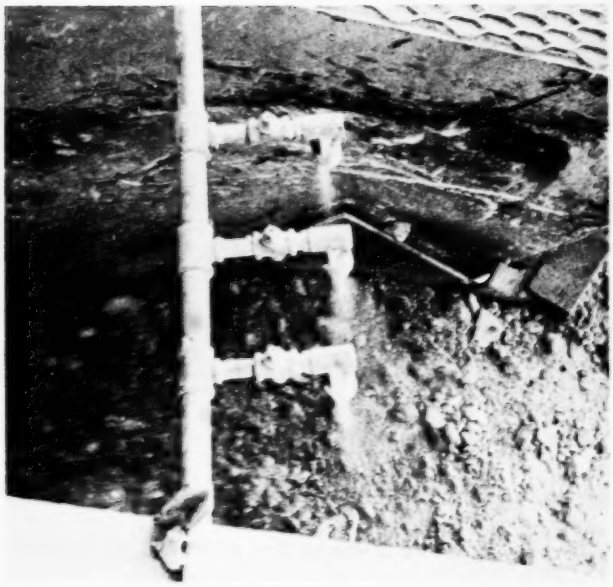


Figure 7

Typical Spray Bar Application

(Photo courtesy of Johnson March)

larger droplet types early in the production and the finer droplet size with the smaller size materials. Choice of spray heads are affected by production rate, stone size, and location ability. The spray bars on which the spray heads are mounted are located with sufficient clearance from the belt, screen, etc. to make sure that moving stone does not impact, trucks or other vehicles are not likely to hit it (as for instance in the loading area of the primary crusher) and so the unit can be observed and maintained with reasonable ease. Sprays are usually located about 3 to 6 feet from the contact point - splashing occurs if too close to the surface and the advantage of a fine spray will be lost, while if spray bars are too far from the surface, crosswinds will have more of a chance to deflect the spray away from its target. The designer usually examines the access problem, stone size and production rate in determining the number, type, and location of the spray positions in a process.

A good figure[5,6] for the amount of solution sprayed on the stone is 1.5 gallons per ton of plant production. If chemicals that reduce the surface tension of water are not used, this figure could be three or four times greater. The 1.5 gallons of solution per ton of production is not applied at one point, rather it is the sum of the solution distributed at various points throughout the plant. Figure 8 shows typical application points for such a system.

Plain water with a surface tension of 73 dynes per cm at 20^{o}C does not exhibit good qualities of wetting, spreading and penetrating. Use of water as the sole spray materials therefore would require more gallons per ton of production than a solution containing a surfactant. When surfactan

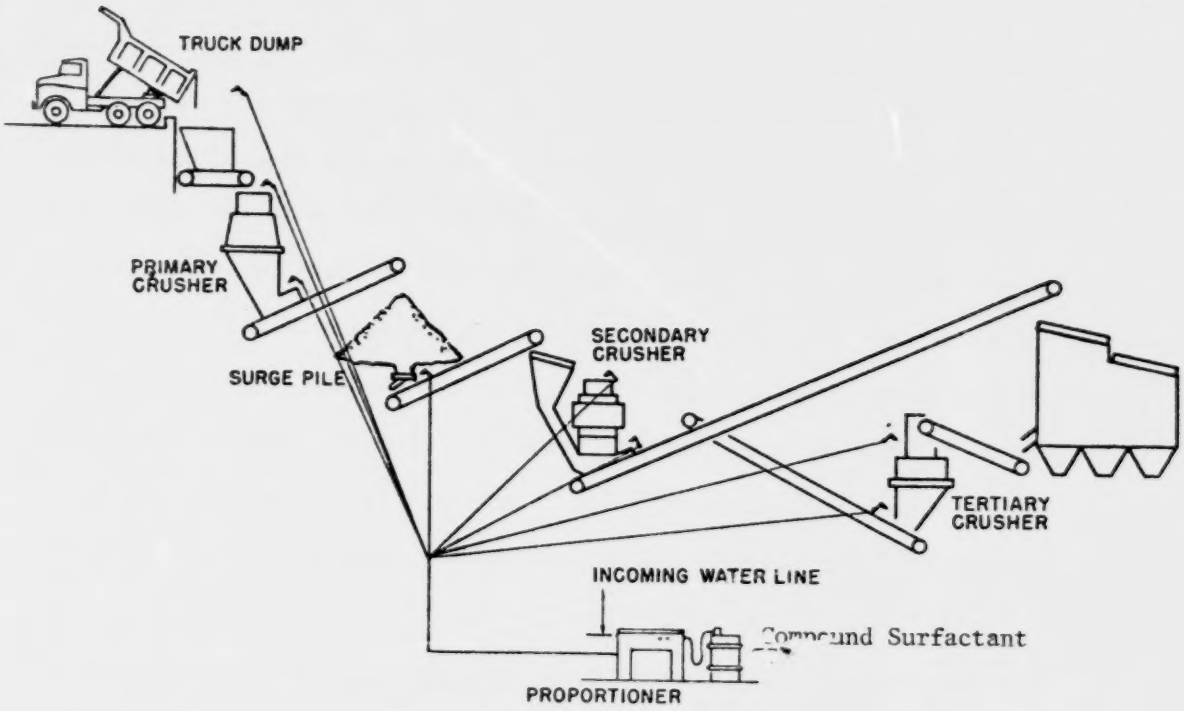


Figure 8

Typical Application Points for a Wet Suppression System in a Crushed Stone Plant

are added, the surface tension of water is reduced to 20 to 30 dynes per cm which greatly enhances the dust suppression since the water is able to penetrate the dust particle creating a cementing action between dust particles so that the agglomerates thus formed are too heavy to become airborne.

"Wetting Agents" is a broad category which covers such items as emulsifiers, solubilizers, detergents, foams, penetrants, thickeners, etc. Dust control compounds, on the other hand, are carefully formulated blends in which one or more special surface active agents ("surfactants") have been incorporated. The molecules of these compounds are composed of two groups exhibiting differing solubility characteristics. One part, usually a long chain hydrophilic or water loving group is usually a sulfate, sulfonate, hydroxide, ethylene oxide, etc. The other group is a long chain hydrophobic or water hating group. When properly proportioned, these compounds effectively reduce the water surface tension.

Wet suppressent systems with surfactant solutions appear effective in dust control although there is no quantitative data to specify the degree of control attained. Figures 9 through 11 indicate the effectiveness of well designed wet suppression systems. Such systems, however, cannot be universally used for dust control. A spokesman[6] for one of the largest companies that makes and installs wet suppression systems stated that in their experience about 75% to 85% of crushed stone operations could use wet suppression systems. Some stone type and product size operations could not use the systems. In these cases, dry collection equipment is used or a combination wet suppression and dry collection.

Figure 9
Before and After Applications of Wet Suppression on a Portable Plant
(Photo courtesy of Johnson March)

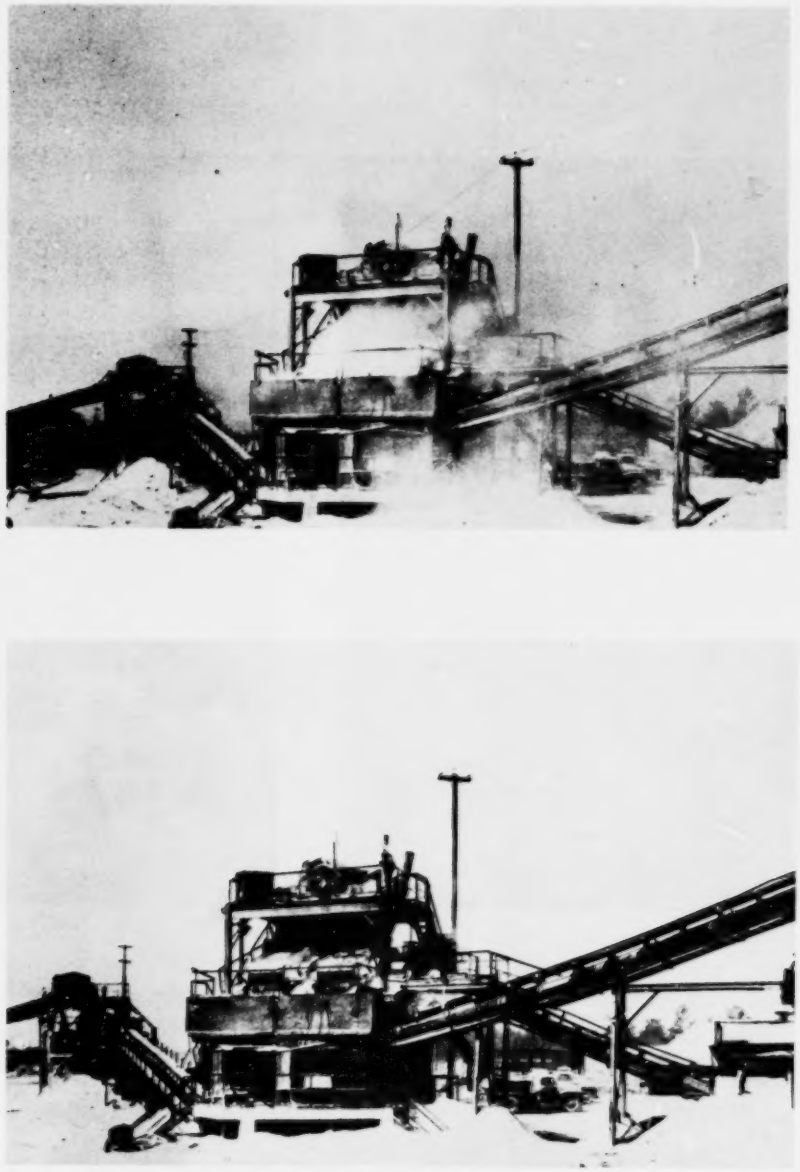


Figure 10
Before and After Wet Suppression on a Screening Operation
(Photo courtesy Johnson March)

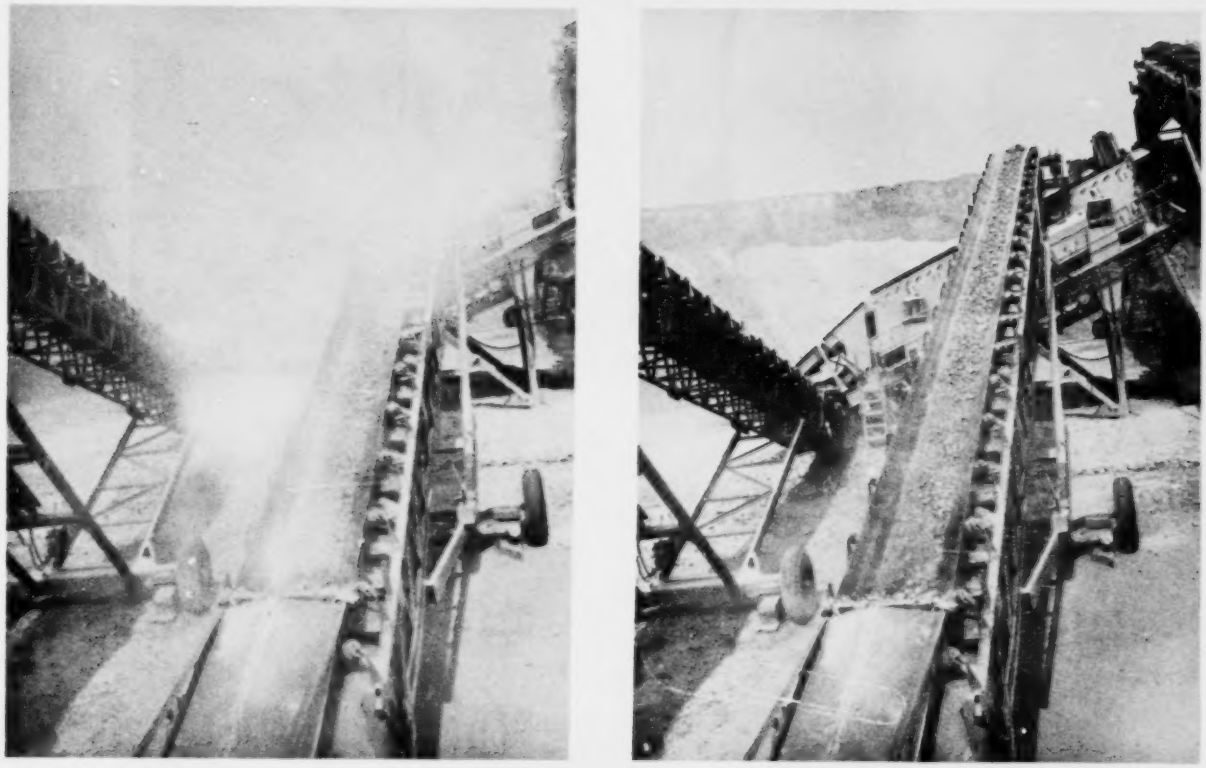


Figure 11

Before and After Wet Suppression on a Portable Crusher-Screening Operation
(Photo courtesy of Johnson March)

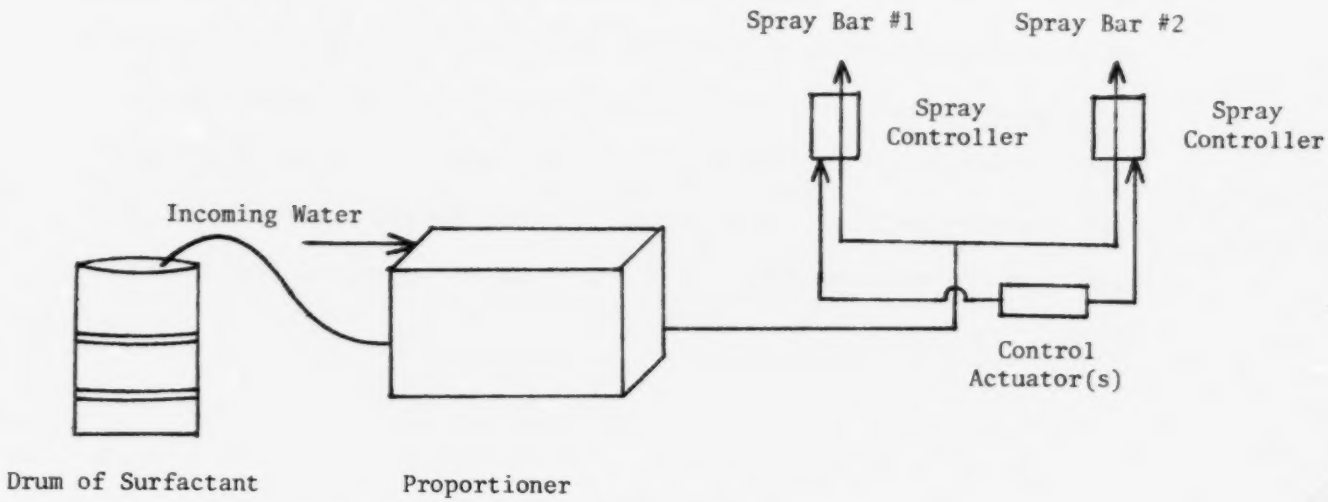
In the initial process stages of production, i.e. primary crushing and screening and secondary crushing and screening, problems associated with wet suppression are minimal. However, when used to control dust at tertiary crushing and screening where small product sizes and screen openings are encountered, problems may arise. The wetted dust tends to blind the openings in fine screens. In agricultural limestone where very fine material is required in a dry state, the addition of water is not practical. Many states also have what is known as a wash out test specification on certain grades of stone. This test is designed to measure and thereby control the amount of -200 mesh (74 microns) particles in the product. A given amount of product is washed in a prescribed fashion and the amount of particles passing a 200 mesh screen weighed. If the weight of these particles exceeds a certain amount of the product weight (usually 1% to 2%), the lot from which the sample was taken is rejected. If the stone is to be used for certain types of concrete products, both the fines and any surfactant remains may have to be washed out of the stone before it is acceptable. This requires an additional plant operation with the need for more water, on the order of several hundred gallons per ton of product processed. The water residue would then have to be treated for solids removal before discharge to surface waters. If discharge is to municipal facilities, a charge based quantity discharge and a surcharge based on solids content may be levied. If the plant discharges into a municipal system that was constructed or upgraded with a government grant under the Federal Water Pollution Control Act, the plant would be assessed both a User Charge and an Industrial Cost Recovery Charge.

A potential problem is occasionally noted relative to a tendency of the surfactant material to cause air voids in concrete and bituminous mixes. No data could be found to identify this as a practical problem on a national basis. Several producers in the Pennsylvania-New York border refrain from using surfactants in their wet suppression systems, but no national pattern or test evidence was uncovered.

System Configuration

The method of suppression described above requires a series of spray bars and nozzles, a supply of surfactant which is proportioned and mixed with the water, a set of connecting pipes, pumps to force the water to the spray heads, and appropriate filters. A method of automatically turning on the system only when material is being produced is required, as is winterizing equipment when the system is to be employed in below-freezing weather.

The system is shown below in schematic with only two spray bars to demonstrate the equipment involved.



The function of the proportioner shown in Figure 12 is to filter the input water if necessary, add surfactant from a drum at the rate of one part to 1000 parts water or more, and develop a pump head of about 150 psi. This pressure is typically used at the truck dump at the front end of the crusher and reduced to about 60 psi at the other spray bars by means of pressure regulators.

The control actuators automatically detect presence of stone on the conveyor and transmit the signal to the spray controllers. The actuators operate on a variety of principles including mechanical displacement of the conveyor belt, weight, electrical interlock with the conveyor drive motors, by measuring the current load to drive motors, and for fine or light weight materials that cause little conveyor deflection or motor drag, by a device mounted on top of the conveyor that is deflected by material on the conveyor.

A spray jet controller is mounted before each spray jet header and consists of a filter and a method of governing the flow of the mixed solution supplied by the proportioner.

Maintenance

According to a report prepared for the U.S. Bureau of Mines by MSA Research Corporation in April, 1974[7], adequate maintenance of dust control systems in non-coal mining and ore processing operations seems to be the exception, rather than the rule. The report contained results of visits to 50 mines and 51 mills (processing plants) of which seven were crushed stone.

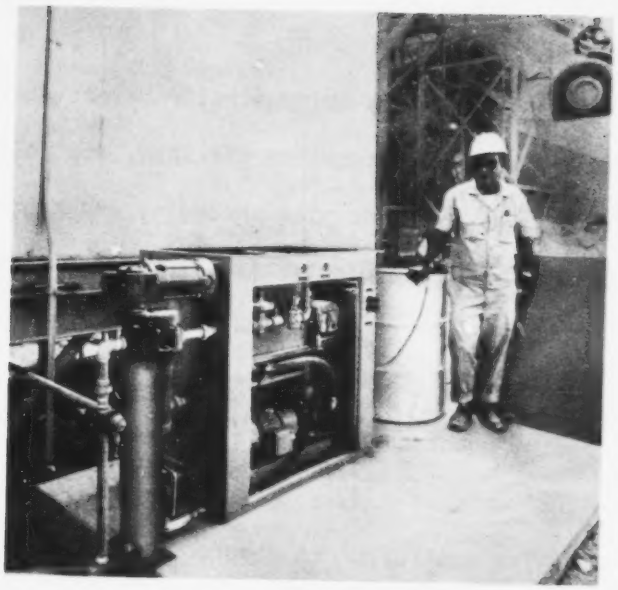


Figure 12

Proportioner, Main Pump and Surfactant Drum
(Photo courtesy of Johnson March)

Where wet suppression systems were employed spray bars were found where the nozzles were either completely clogged or clogged to the point where they were ineffective. In most cases, this problem was due to inadequately maintained water line filters. The report was generally critical of the state of maintenance of control equipment which was reported in a poor state of repair in relation to general plant.

As with any dust control device, a wet suppression system must be adequately maintained to keep its efficiency at peak levels. The principal source of trouble is in foreign material blocking the liquid flow. If the system operates on city water the filters can go for months without serious effects whereas if the water is from wells, rivers, or ponds more maintenance will be involved. Although the system details vary from manufacturer to manufacturer there are generally three filters, one at the proportioner, one at each spray controller, and one in each spray. The main filter in the proportioner demands the most attention because it is first to "see" the conditions of the supply water. One manufacturer[8] suggests the following maintenance procedures. After some experience is gained with the system the maintenance schedule can be adjusted. For instance if the strainer baskets remain clean after several weekly checks this procedure could be extended. On the other hand, the strainer basket in the proportioner might need more frequent attention if the input water has a high amount of solids.

DAILY MAINTENANCE

1. At time of start-up of Proportioner
   a. Check pump discharge pressure.
   b. Check operation of level control valve.
   c. Check operation of surfactant pump.
   d. Check level of surfactant compact in drum.
   e. Check operation of Inlet Water Filter.
2. Visually check spray pattern and direction of all spray jets. Clean and adjust as necessary.

WEEKLY MAINTENANCE

1. Clean strainer basket in each Flow Controller.
2. Clean strainer basket in the Proportioner.
3. Check operation of all Automatic Spray Controls.

GENERAL

1. Lubricate all equipment requiring lubrication, including wheels on Automatic Spray Controls, when other plant equipment is lubricated.
2. Before first freezing weather, check all heating equipment. (Winterizing is accomplished by wrapping electrical heating tape around pipes much the same as in winterizing residential.)

More detailed information is usually contained in the System and Equipment Operation and Maintenance Instructions generally furnished by the vendors with the equipment.

Portable Plant Applications

Spray systems are readily installed in portable plants, and by the use of flexible connections from the proportioner to the spray headers, can accomodate changes in plant layout. In cold weather there is a problem in winterizing such installations by using heating tape because of the flexible nature of the hose and its heat transfer characteristics compared to metal piping.

In areas where arid conditions are encountered, there are special problems on water needs for the system which must be considered in setting up the plant. As noted previously, if a surfactant is used, the total water needs for a plant would be about 1.5 gallons per ton of product. If a surfactant is not used, water requirements would be 4 to 5 gallons of water per ton of production.

There are several regions of the country which have arid conditions and where portable plants are extensively used. Eastern Oregon, for example, is one such region of low precipitation and with high reliance on portable plants.

Stone crushing operations in this region might obtain water from three sources; ground water (wells or old quarries that have intercepted the water table), surface water (rivers, streams, lakes, ponds, etc.), or tank truck. Water wells may be constructed when a plant is to remain in one location for

a period of time or if the plant returns periodically to the location. This, of course, means that sufficient ground water supplies must be available to meet the plant's needs, and because ground water occurs sporadically in Oregon, well drilling is relatively uncommon. The cost of drilling a well is about $20 to $25 per foot plus $15 per foot for casing (steel). Water when available via wells occurs within 100 to 300 feet of the surface which would cost between $3400 (drilled to 100' and cased to 75') and $10,000 (drilled to 300' and cased to 225').

Surface water supplies can be used when they are available. A plant could purchase water from the owner of a farm pond. In other instances, a stream may be temporarily dammed to serve as a source of water for the crushing operation. The cost of water is about $10 per 1000 gallons or about $0.01/gallon. This is the prevailing cost of water in both Eastern and Western Oregon according to Oregon sources.[10]

When neither ground water nor surface water supplies are available to a stone crushing operation, water can be supplied by tank truck. These tank trucks can be purchased or rented by the crushing plant. Crushed stone plants with their own water trucks, are frequently of the "home-made" variety. That is, a tank will be mounted on the bed of an old truck and used for hauling water. The cost is less than half of a new truck. The cost of purchasing a new tank truck can be from about $22,000 for a 4,000 gallon truck to $43,000 for a 10,000 gallon truck (either diesel or gasoline engine powered). The operating cost of one of these trucks is about $0.02/ton of product (this includes labor, rent, fuel and servicing).

Another way of approaching the cost is to use rental figures set forth in a state's method of adjusting highway construction contract figures for unanticipated additional work. In Oregon, for example,

according to Oregon highway personnel[9] when the state requires supplemental work done and desires to use a contractor's equipment, there is a set payment schedule on what is known as a "force account". This schedule shows that on a weekly basis the contractor would be paid an amount of $399.65 + 15% for overhead and profit for the use of a diesel powered gravity type sprinkling truck (the closest to a water truck on the schedule). Assuming profit at 1/2 of the 15% figure, the weekly cost would be $430 or $10.75 per hour prorated over a 40-hour week. This figure includes all expenses, including fuel and oil, but excludes labor. Labor at $12.35 per hour including markup is, according to contacts with Oregon highway personnel, a realistic labor rate to drive the water haul truck to and from a pick-up point. Since only about 2 hours per day would be spent in driving the truck, the hourly prorated amount would be 2/8 of $12.35 or $3.09. The total hourly cost would be $10.75 + $3.09, or $13.84. For a 300 ton per hour plant (one that could be supplied by one 4,000 gallon truck on one trip per day) the cost per ton capacity would be $13.84 ÷ 300 tons or 4.61¢ per ton. To this must be added the cost of the water.

Despite the fact that there is a considerable difference in precipitation between eastern and western Oregon, adequate water supplies are available if trucking is done and the prevailing rate of about $10 per 1000 gallons of water holds in both regions[10]. The water cost, assuming 1.5 gallons per ton of product would add 1.5¢ to the trucking cost for a total of 6.11¢ (4.61¢ + 1.5¢) per ton of stone crushed for a 300 ton per hour plant. For a 600 ton per hour plant the cost is 4.45¢ (see Table 3) per ton added.

Therefore, the trucking cost alone more than doubles per ton control costs by wet suppression of a plant required to haul water over a plant which is not required to haul water. This cost of control, however, viewed in relation to product cost and market posture of the industry is not unreasonable. While operations using wet suppressent methods in arid regions will experience higher operating costs, the inelastic nature of the market and the strong effect transportation exerts on price indicates that such costs can be passed through with negligible change in product demand.

A portable 300 ton per hour plant using a wet suppression system would experience control costs of 9.84¢ (see Table 3) per ton if water had to be hauled. The price of crushed stone FOB quarry is on the order of $2.50 per ton. It varies according to location of the quarry and size stone produced. The average price of 1975 stone received by one state depot in Pennsylvania in response to competitive bids was $2.41 for 2A stone, and 2.73¢ for 1B. Oregon reported[9] an average FOB price from four cities (Eugene, Grant's Pass, Albany, and Portland) of $2.37 for 3/4" stone. The control cost is 4.2% of this average product cost. This 4.2% pass-through increase would not affect the overall demand for stone because the price of stone has little effect on the price of its major uses. This can be seen from data submitted by the crushed stone industry in 1973 to the Cost of Living Council which concluded that a 10% increase in stone price would have had little effect on its users.

Table 3

MODEL WET SUPPRESSION COSTS

FOR PROCESS PORTIONS OF CRUSHED STONE PLANTS[1]

Capital Costs for Installed System

	Small Plant 300 Tons/Hr.	Large Plant 600 Tons/Hr.
Wet Suppression Equipment	$58,643	$69,108
Annualized Capital Costs (12.50% of Capital)	$ 7,330	$ 8,639
Operating & Maintenance[2]		
Electricity @ .04/KWH	$ 115	$ 288
Maintenance Operation & Supplies	$14,048	$22,398
Total Annualized O&M	$14,163	$22,686
Total Annualized Cost (Capital + O&M)	$21,493	$31,325
Cost/Ton (excluding water hauling & water costs in arid regions)	3.73¢	2.72¢
Added Cost/Ton for water & hauling in arid regions	6.11¢	4.45¢

1. Basic data obtained from: Evans, Robert J., "Methods and Costs of Dust Control in Stone Crushing Operations", Bureau of Mines, U.S. Dept. of Interior, IC 8669, September 13, 1974, adjusted as follows:

   (a) Electrical operating costs increased from $.015KWH to $.040/KWH
   (b) Operating time increased from 40% to 80%
   (c) Capital costs and maintenance material adjusted to June 1977 by Wholesale Price Index for General Purpose Machinery & Equipment (33% June 1974 to June 1977)
   (d) Operating and Maintenance labor adjusted to June 1977 rates by use of U.S. Dept. of Commerce Survey of Current Business Conditions for Private, Non Agricultural Businesses (24.3% from June 1974 to June 1977)

2. (a) Supplies do not include water costs.
   (b) Surfactant costs adjusted from $2.60 per gallon to $5.00 per gallon to reflect current prices.

At that time the average price of a cubic yard of concrete in place was $125. The average price of the stone at the quarry was $1.73 per ton; FOB delivered it cost approximately $3.00. This was less than 1.4% and 2.5%, respectively, of the price of the concrete. Thus a 10% increase in the price of the stone at the quarry would have a negligible effect on the per yard cost of concrete in place, increasing the price by $.17. The effect of a 10% increase in the price of stone would have about a $7 increase in the price of a $30,000 home; a $500,000 building would be increased by $180, a $400,000 per mile highway by $640 per mile and a $360,000 school building by $140.

Transportation costs make the industry one of local competition with the notable exceptions of some stone sources with access to cheap water transportation. Stone transportation costs range roughly from 12 to 19¢ per mile for truck transportation, so that proximity to market is the major competitive determinate when yard prices are several dollars per ton. Because of the demand inelasticity and this high impact of transportation costs for the finished stone on-site delivered price, one would expect negligible decrease in demand for stone with the addition of the control costs, and a good ability of a producer to recover the cost by price adjustments.

Control Costs

Typical control costs for two size plants using wet suppression techniques are shown in Table 3. To these figures must be added the water costs developed above if the plant is in an arid region. (Oregon figures used in the table).

Baghouse Systems

Dust in process operations of crushed stone plants is often controlled by dry collection techniques using appropriate methods to capture the dust and transport it to one or more baghouses. Whether a central baghouse is used or two separate baghouses depends principally on the layout of the plant and is decided on the basis of installation and operational economics. Baghouses must be used in those operations where stone type and/or small product size preclude the use of wet suppression techniques.

Principal System Components

A baghouse system in crushed stone process operations can be examined in the light of the four functions which make up the total system design:

- Pick up design
- Ducting design
- Filtering design
- Filter catch handling

Pick Up Design:

This is a key factor in a dry collection system. If the dust that would otherwise become fugitive is not properly "picked up", the system will fail in its job. A pick up system consists of a hood or enclosure and an indraft sufficiently high to entrain the dust that may otherwise become fugitive. The indraft velocity in feet per minute multiplied by the area of the hood opening in square feet yields the volume flow in cfm required to adequately vent a particular dust emission point to the connecting duct

and thence to the baghouse. There is general agreement on indraft design. A minimum draft flow of 200 fpm at pick up points is frequently used. Some general rules applied at various operational points are:

1. Volume flow rate at conveyor transfer points of 350 cfm per foot of belt width for belt speeds of less than 200 feet per minute and 500 cfm per foot of belt for speeds over 200 feet per minute.
2. Volume flow rates of 100 cfm per square foot of casing cross section for bucket elevators.
3. Volume flow rates of 50 cfm per square foot of screen area on vibrating screens either single or multiple deck.

Not only must the necessary indraft flow be provided, but the emission point should be covered as completely as possible to avoid the effects of wind interference which would otherwise blow the particle away. For example if a 200 feet per minute (fpm) indraft velocity is used, a cross wind of 10 miles per hour would exert a cross draft of 880 feet per minute on the particle. Its resulting trajectory rather than being up and into the hood and to the transfer duct would then be at 87° to the intended direction, and would likely not be captured. Good enclosure and hood design are indicated in Figures 13, 14 and 15.

It is common practice to use abrasion resistant rubber liners around hoods venting crushers or transfer points (see Figure 16). These liners are often constructed with slits in the lower edges so that they can be slightly larger than the openings, but not impede material flow on conveyor access points and crusher openings. It is good practice to cover conveyor belts to prevent dust being carried away by the wind. Screen houses are frequently enclosed and vented from the top.

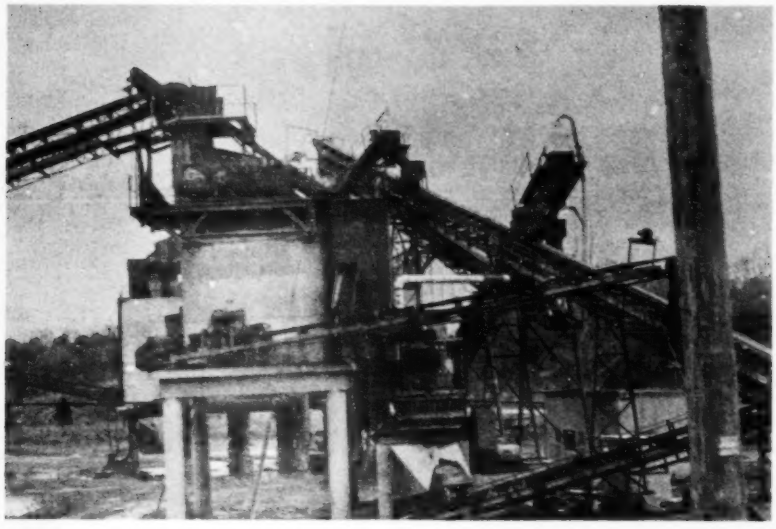


Figure 13
Crushed Agricultural Line Operation Showing Good Enclosure Design at Transfer Points
(Photo courtesy of PennDER)

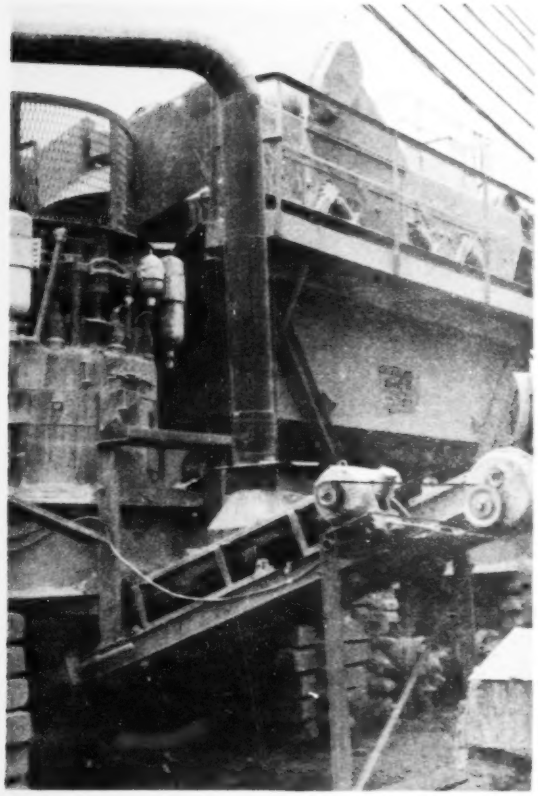


Figure 14
Good pickup design on a portable plant
(JACA Photo)

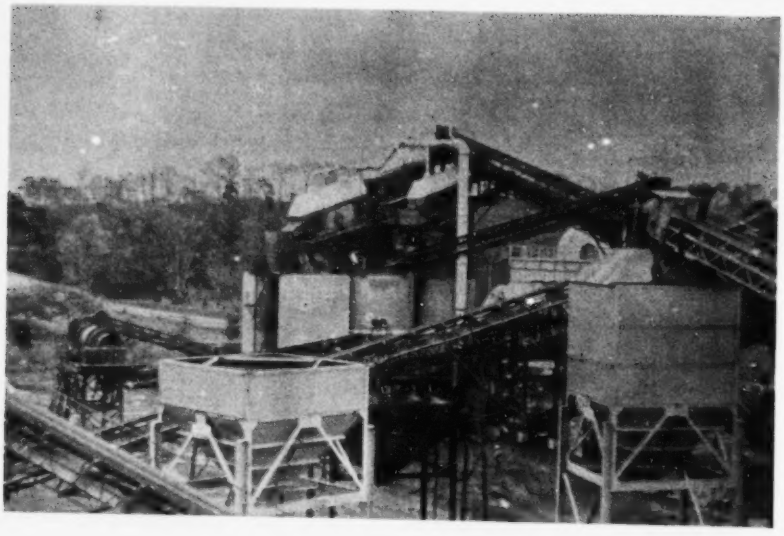


Figure 15
Good Hood Design on Screening Operations of an Agricultural Crushed Stone Plant
(Photo courtesy PennDER)

Figure 16
Hood With Rubber Skirt at Secondary
Crusher Output
(JACA Photo)

Ducting:

Air velocities in the ducts leading from the hoods to the baghouse are typically 3500 to 4500 fpm. This velocity is needed to keep the particles entrained in the air stream rather than settling out at bends, turns and connecting points in the ductwork system. Tight bends should be avoided both because particles may be knocked out there and because of abrasion of the metal walls. In addition bends and abrupt connecting of ductwork introduces frictional air losses which must be compensated for by larger fans and motors. Vibration is also a problem at crusher and screen pick ups which is frequently solved by using a flexible section at the inlet to minimize damage.

Fabric Filters:

The actual filtering operation in crushed stone operations is a reasonably simple one. Problems such as high gas temperatures and corrosive atmospheres that constitute design problems in many baghouse installations are not present. Nomex and fiberglass bags need not be used, insulation is not generally required, and temperature adjustment and temperature safety devices are not called for. Sizing, as in any baghouse, remains a critical design factor. The ratio of the amount of air by volume to the lateral area of the bags, the so called air-to-cloth ratio, can vary from 2 or 3 to 1 for mechanically shaken bags to 6 or 7 to one for pulse air type units. In the mechanically shaken bag method the baghouse is larger because of the lower air to cloth ratio and the fact that one compartment must be taken off stream for shaking, while in the positive air blowdown the full system is essentially always on stream. While mechanical shake baghouses are larger for a given gas handling capacity, they require less in the way of bag cleaning equipment. Air blowdown requires sets of solenoids and air headers on each row of bags, air venturis for each bag, and an air compressor to supply the necessary blow down air.

The fan is usually located on the side of the baghouse opposite the baghouse inlet - the "clean side" of the system. The air is pulled through the baghouse giving rise to the term negative pressure baghouse. Thus, the fan blades do not experience the wear they might otherwise if the fan was located on the dirty side of the system. The negative pressure aspects, however, means that the baghouse should be well sealed, and leaks in ducting promptly repaired.

Dust Disposal:

What is done with the captured fines varies from plant to plant depending on the product being manufactured and "outside" markets for the fines in that particular area.

Dust hoppers usually have an air lock valve emptying the bin either into a truck or via a screw conveyor or a pneumatic conveyor to some other direct use or storage for future use. For instance, the baghouse controlling the primary crusher of report 75-STN-3[11] periodically discharged the catch during the cleaning cycle through an air lock onto the covered conveyor leading to the secondary crusher. Its discharge of about 10 tons daily is fed directly back into the process. The second baghouse which collects material from secondary and tertiary crushing and screening operations discharges directly into an agricultural stone bin and is used as final product.

The baghouse reported in 75-STN-78[13] discharges a total of about four tons per day into a truck. The material was then used as choke material in road based stone.

Whether the material is reintroduced into the product, sold separately as fines or discarded in a suitable dump site depends on the markets open to a particular plant.

Maintenance

Failure of a conveyor, a crusher, or screening operations would constitute immediate plant problems, production might stop, and if the nature of screen failure involved holes in the screen out of size rejects would mount. Therefore these portions of the plant receive preventative maintenance to reduce potential downtime. If failure occurred prompt attention would be taken to restore production and assure quality control. The dry pollution collection system is not integral to the plant - the plant can produce quality stone even if the pollution control equipment is not functioning properly. Therefore there is a temptation to devote more maintenance attention to the productive processes rather than the control process. This was noted by Reference 7, a study on control efficiency in non coal mines, both surface and deep, that stated, "It is obvious that production maintenance has priority over dust control maintenance."

Maintenance starts with enclosures and enclosure skirts. As mentioned earlier in this section proper enclosures plus an adequate indraft is essential for capture of what might otherwise be fugitive dust. Enclosures can be quickly examined - once a week should be sufficient - to detect frayed skirts or loose or ill fitting enclosures.

Ducting should have suitable clean out holes which should be examined for dust build-up first on a weekly basis and then adjusted to more or less frequent cleaning depending on the amount of build-up. Ducting should also be inspected weekly for holes and separations. If the enclosures and skirts have a reasonable fit and the ductwork is clear and without holes the remaining points to inspect are the baghouse and operating mechanisms and the air moving apparatus.

The amount of air moving through the system is important because the amount of air for a given ductwork and hood design determines indraft and duct conveying velocities. If there is reduced airflow the system may be working ineffectively. Airflow and systems operation can be checked very easily by the aid of two inexpensive instruments, costing less than $100 each - a simple pressure gauge (either u-type water gauge, or magnehelic) and a hand tachometer.

The pressure gauge is used to measure system pressure drop and pressure drop across the baghouse. The tachometer is used to measure the fan speed.

As air moves along ductwork, especially at restrictions, joints, bends etc. it encounters a resistance to flow reflected in a static pressure drop There is also a drop in moving through the baghouse, and around any dampers that might be in the system. System resistance can increase if dampers are incorrectly set, bags in the baghouse blind, and ducts become obstructed. If the system pressure drop increases the capacity of the system to handle the air flow has decreased and it will not have sufficient indraft.

Since the air handling system is open to atmosphere at both ends, the system pressure drop is numerically equal to the static pressure across the fan. It is much easier to measure the static pressure drop across the fan than to measure all the individual pressure drops that make up the system pressure drop. A 3/8' pipe metal static tube can be inserted and welded into the outlet and inlet side of the fan positioned opposite to the direction of flow to measure only the static pressure. The inlet side is first connected via a suitable flexible tube to the low pressure end of the gauge, and a reading taken. The flexible tube is then attached to the out-

let side of the fan and the high pressure end, and a second reading is taken. The difference is the pressure drop in the system. If these readings are taken when the system is known to be in good operative condition, a difference of $\pm$ 20% or more at a later date from the initial condiction at satisfactory operation indicates some system problem. Lower pressures point to leaks between the dirty and clean side of the baghouse and/or large holes in the ductwork, or reduced fan speed. Higher pressures indicate such problems as obstructions in the ducts, blinding of filter bags in the baghouse and dents in the ductwork.

Test points for static pressure should also be provided across the dirty and clean sides of the baghouse. A pressure gauge can be permanently placed there, and is frequently included with the equipment. This narrows the diagnosis to the baghouse. If pressure is lower than normal this can mean that a hole or tear has developed in one or more of the bags, a clamp has become loose at the plenum spearators, a separation has occurred in the seal or weld of the plenum separator. If the pressure is higher than normal it can mean that the bags are blinding either because of damp material or incomplete cleaning.

The tachometer can be used to measure the fan RPM by pressing the tachometer tip firmly against the center of the fan shaft while the plant is in operation. Since most fans encountered in stone crushing operations are positive displacement devices the amount of air handled is directly proportional to the speed of the fan. A decrease in fan speed which might be due to operational wear or stretch of the belts used in the drive will result in a decrease in air handling capacity of the system including the critical indraft portion.

Bag cleaning mechanisms should be checked about once a week. Mechanical shakers should be checked for lubrication and wear. Positive pressure air cleaning devices should be checked for solenoid operation, and compressor performance about once per week. Manufacturers of compressors and bags provide maintenance instruction with their equipment. These are usually broken down into daily (mostly visual), weekly, and monthly maintenance procedures. Special sections are frequently included on preparations for lengthy shutdown periods (viz. over winter months in northern states) and turn on.

Control Costs

Control costs for a model plant fabric filter system installed is set forth in Table 4. The plant installation estimated was shown in Figures 1 and 2.

Portable Plant Applications

Portable plant operations with fabric filter systems are faced with certain problems if frequent plant movement is required.

Five portable stone crushing plant manufacturers were contacted regarding baghouse systems for portable plants. None offered baghouses as a standard part of their portable rock processing plant line. Three of the manufacturers who make portable asphalt plants offer such units integral to their portable plant line. We were also told by two companies[1,2] which serve only the after market in control systems and who offer both wet suppression and baghouse systems that they have never applied baghouses to

Table 4

MODEL FABRIC FILTER SYSTEM COSTS

FOR PROCESS PORTIONS OF CRUSHED STONE PLANTS[1]

Capital Costs for Installed System

	Small Plant 300 Tons/Hr.		Large Plant 600 Tons/Hr.	
Fabric Filter System Equipment Costs Installed	$125,922		$200,802	
Annualized Capital Costs (12.5% of Capital)		$15,740		$25,100
	Operating & Maintenance[2]			
Electricity @ .04/KWH	$ 8,083		$15,110	
Operations & Supplies	$19,589		$30,153	
Total Annual O&M		$27,672		$45,263
Total Annualized Cost		$43,412		$70,363
Cost/Ton		7.54¢		6.11¢

1. Basic data obtained from: Evans, Robert J., "Methods and Costs of Dust Control in Stone Crushing Operations", Bureau of Mines, U.S. Dept. of Interior, IC 8669, September 13, 1974, adjusted as follows:

   (a) Electrical operating costs increased from $.015KWH to $.040/KWH
   (b) Capital costs and maintenance material to June 1977 by Wholesale Price Index for General Purpose Machinery & Equipment (33% June 1974 to June 1977)
   (c) Operating and Maintenance labor adjusted to June 1977 rates by use of U.S. Dept. of Commerce Survey of Current Business Conditions for Private, Non Agricultural Businesses (24.3% from June 1974 to June 1977)

2. Filter bags adjusted from $8.60 to $9.00 per Dacron bag to reflect current prices.

portable plants although both had supplied wet suppression systems to many portable plants. The difficulty of applying a baghouse system to portable plants does not stem from making the baghouse proper portable since that is frequently done for asphalt concrete plants whose configuration is constant and where only one (in the case of drum mix plants) or at least no more than three or four duct connections (in hot mix asphalt batch plants) to the plant are involved. In portable stone processing, difficulty arises from the multiplicity of ductwork connections and supports, different plant lay-outs at new sites, and resulting changes in dust loads.[12] This can be demonstrated by examining one plant in Pennsylvania, and one located in Maryland.

Both of these plants consist of three portable units. The plant located in Pennsylvania produced about 2000 tons per day comprised of five different product sizes. The operation consists of a primary impeller crusher, secondary crusher and double screen deck and tertiary cone crusher and triple screens. There are seven pick-up points, four in the secondary section and three on the tertiary.

The Maryland unit produces about 1600 tons per day comprised of two products. It includes a primary jaw, a single shaker screen, and a secondary cone crusher with double-deck screens. There are eight pick-up points, one on the primary, two on the shaker screen and five on the double-deck and secondary crusher.

The ducting from both operations is quite extensive and is supported by outriggers welded to various pieces of operating equipment (see Figure 17) or ground mounted A frames. The pick up hoods are also attached to operating equipment and often have a flexible section to help dissipate equipment vibration. (See Figure 18). Some connections are welded directly to pieces

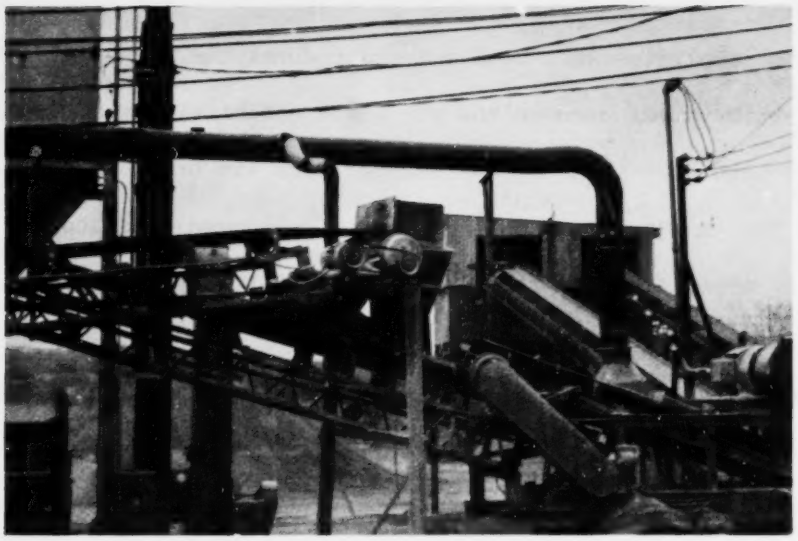


Figure 17

Outrigger Support on Far Left of Duct and Ground Mounted Support on Right. Center Input Duct Shows Poor Design with Three Short Radius Bends, and a Perpendicular Duct Intersection. Wear is Evidenced by White Sections That are Taped.

(JACA Photo)

of equipment as shown in Figure 19.

The baghouses at both locations were tall units having 132 bags each arranged in 11 rows of 12 bags. (See Figures 22 & 23). In shipment they were designed to be laid on their side on a flat bed. The tall narrow configuration simplifies dust load out and reduces the number of air headers and air solenoid valves used in the air pulse cleaning system. In the Pennsylvania plant the baghouse was mounted with tie brackets on a concrete base while the Maryland plant was placed on rail-road ties and secured with four guy wires from the top of the baghouse to a power pole and parts of the stone operating equipment.

Difficulty is encountered in breaking down this equipment and reinstalling it at another location. The A frames must be dismantled and the ducts must be cut into pieces that can be stored for highway travel. The outriggers and ducts must be cut free. It is estimated that this dismantling and reinstallation plus the same for the baghouse essentially doubles the time normally required to move the plant when configuration at the new site is identical to the old. The most difficult problem in such reinstallation is lining up the ductwork with the holes cut in the operating units and the various hoods. In the Pennsylvania plant, duct connections are made to two operating units which are on long flat beds which are positioned by truck, the dollys removed, and the units cribbed as shown in Figures 20 and 21. The Maryland system requires interconnections to three units. It is difficult to maneuver the equipment beds to the position where seven or eight ductwork connections can match up. Field cutting and fitting then must be undertaken to perfect the fit.

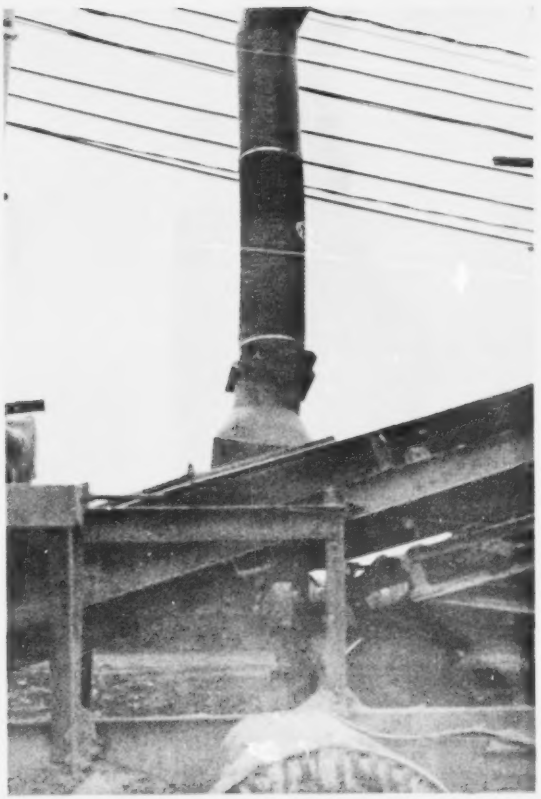


Figure 18
Flexible Section Between Hood and
Duct Takeoff on Secondary of a
Portable Plant
(JACA Photo)

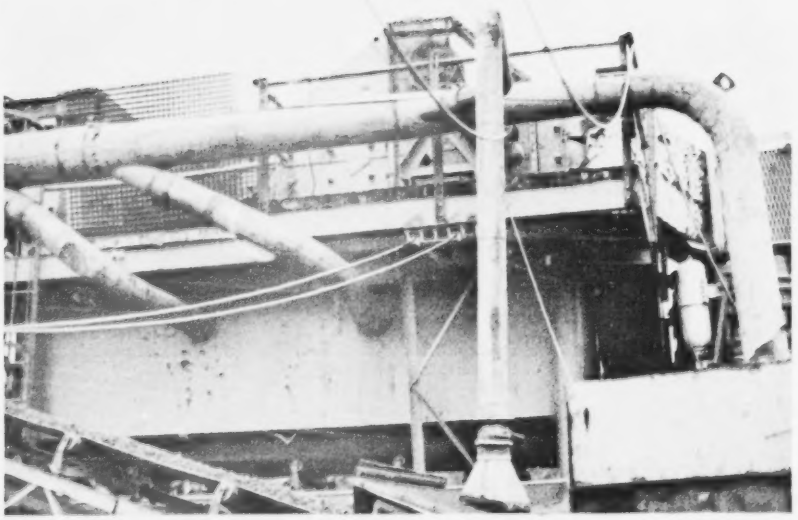


Figure 19
Ductwork Connections to a Tertiary Triple Screen Unit of a Portable Plant.
Holes Were Cut in Unit and Duct Welded in. Duct Radius and Intersection
Points Show Good Design
(JACA Photo)

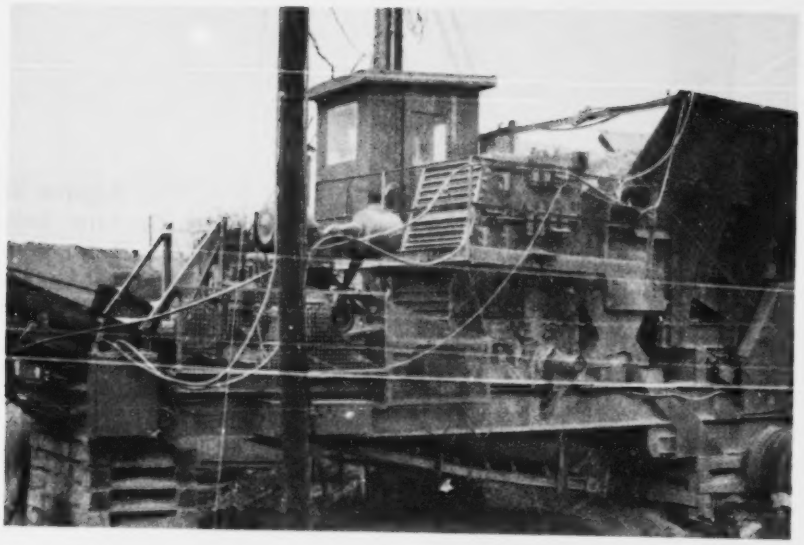


Figure 20
Cribbing on Primary Impeller Type Crusher in a Portable Plant. Load-in Hopper Can be Readily Broken Apart at Bolted Sections During Transportation of Crusher
(JACA Photo)

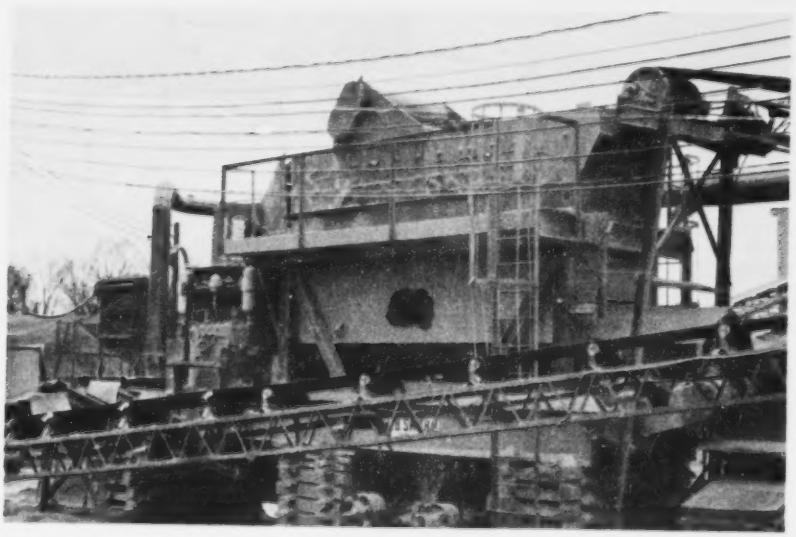


Figure 21
Extensive Cribbing on Tertiary Cone Crusher With Triple Deck Screens
(JACA Photo)

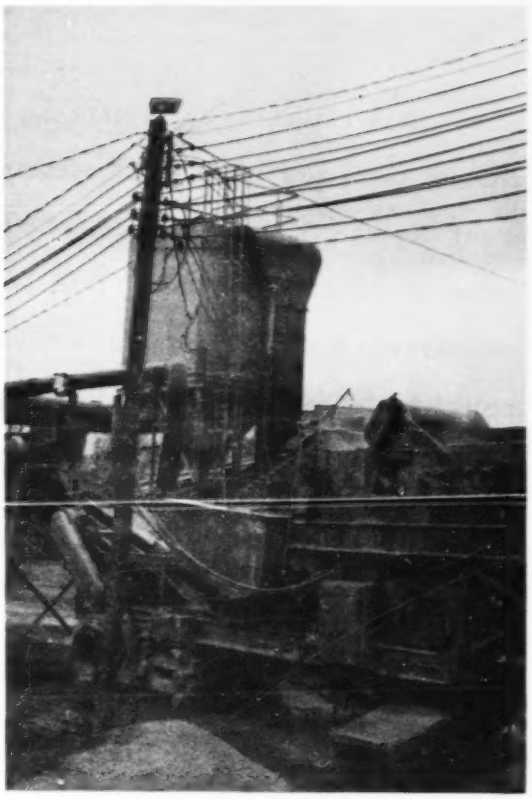


Figure 22
Tall Narrow Baghouse in Background on a Portable Plant

Baghouse attached to frame mounted on concrete slab. Caged ladder and handrails in accordance with OSHA. Bin empties into truck. Note unusual design of exit stack which exits from clean plenum of the baghouse (top of filter house) and then runs horizontally (view obscured by foreground equipment)

(JACA Photo)

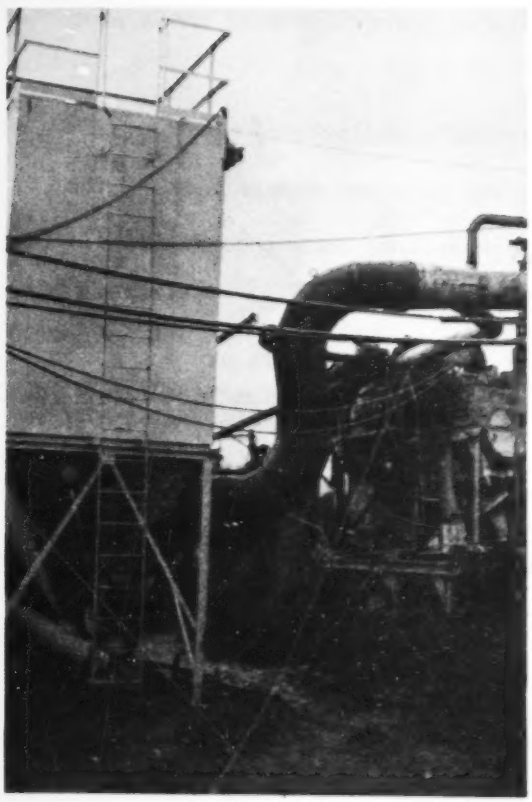


Figure 23
Tall Narrow Baghouse Used With a Portable Plant

Baghouse has been placed on ground and steadied by guy wires. Baghouse empties from screw at the bottom of the house going to the left. Filter catch is merely piled there and protected by a tarpaulin. Damp condition of this site required use of system less than 10% of the time. In dry areas this arrangement would not be adequate.

(JACA Photo)

This situation is greatly aggravated if the stone processing operation changes configuration. Local terrain limitations and or product requirements might dictate that the process units comprising the operation be grouped in other than a straight line. This is not infrequent and might involve a semicircle, T, or L configuration. In this case the ductwork would require redesign and considerable installation modifications.

Another difficulty, not as dramatic as the reconfiguration problem lies in the necessity to keep the ductwork compact for shipment but providing low air movement friction loss and wear. A rule of thumb in duct design is to have radius turns equal to at least two diameters, and to keep intersections of ducts at 30^{o} or less. These practices reduce wear on the ductwork and fans and motors and conserve energy but make the system more difficult to transport.

While astute design can affect a reasonable engineering compromise between system life and energy needs on the one hand and compactness on the other, the problem of ducting for multiple connections in a reconfigured deployment of process equipment is of more serious proportions. It would appear to be a principal reason for the fact that such systems are not generally offered as a part of the overall original process equipment.

Combination Wet Suppression and Baghouse Systems

When water availability is not a problem and where fine size products that really agglomerate are being made (crushing and screening operations on -1/4" particles) a combination system is often employed. Wet suppression is generally used at the initial portions of the process, i.e., the primary crushing and screening operations, reclaim feeders and conveyor transfer

points. Emission points following these process activities such as secondary and tertiary crusher and screen and recirculating conveyors would be controlled by a baghouse collector. Combination systems have higher annualized costs than full wet suppression systems, but less than fully dry systems when water is readily available. When water must be trucked in the added costs of the hauling must be included in the analysis. Since water is applied to only a portion of the system, the water use will be about 40% that of the total wet suppression system or about 2¢ per ton which would be added as in the figures in Table 5.

The combination system thus presents a practical alternative to a fully dry system in that the acquisition cost is less than a fully dry system. It also has the advantage of using less than half the water requirements of a fully wet system. This is an advantage in arid regions. In addition, it eliminates the problems of screen clogging when fine size material is being processed.

Electrostatic Spray Systems

Dust control by wet suppression techniques in crushed stone operations was practiced for at least thirty years, and baghouse dry collection widely used for more than ten years. Electrostatic spray systems in contrast are very recent and consequently little data on field experience is available. The authors know of no electrostatic spray system with practical demonstrated operability in an outside environment in a stone crushing operation. The system has future promise in certain applications in stone quarries however where very fine dusts are involved and where wetting as employed in wet dust suppression is unacceptable. The experimentally demonstrated ability to handle small particles with very little water justifies a more detailed description of this new control approach.

Table 5

MODEL WET SUPPRESSION - FABRIC FILTER SYSTEM COSTS

FOR PROCESS PORTIONS OF CRUSHED STONE PLANTS[1]

Capital Costs for Installed System

	Small Plant 300 Tons/Hr.		Large Plant 600 Tons/Hr.	
Fabric Filter and Wet Suppression Equipment Installed	$107,852		$132,840	
Annualized Capital Cost (12.5% of Capital)		$13,482		$16,605
Operating & Maintenance[2]				
Electricity @ .04/KWH	$ 2,909		$4,694	
Maintenance, Operation & Supplies	$18,396		$25,778	
Total Annual O&M		$21,305		$30,472
Total Annualized Cost (Capital + O&M)		$34,787		$47,077
Cost/Ton (excluding water)		6.04¢		4.09¢
Cost/Ton for water in arid regions		2.44¢		1.78¢

1. Basic data obtained from: Evans, Robert J., "Methods and Costs of Dust Control in Stone Crushing Operations", Bureau of Mines, U.S. Department of Interior, IC 8669, September 13, 1974, adjusted as follows:

   (a) Electrical operating costs increased from $.015KWH to $.040/KWH
   (b) Operating time increased from 40% to 80%
   (c) Capital costs and maintenance material to June 1977 by Wholesale Price Index for General Purpose Machinery & Equipment (33% June 1974 to June 1977)
   (d) Operating and Maintenance labor adjusted to June 1977 rates by use of U.S. Dept.of Commerce Survey of Current Business Conditions for Private, Non Agricultural Businesses (24.3% from June 1974 to June 1977)

2. (a) Supplies do not include water costs.
   (b) Surfactant costs adjusted from $2.60 per gallon to $5.00 per gallon to reflect current prices
   (c) Filter bags adjusted from $8.60 to $9.00 per Dacron bag to reflect current prices

As is not infrequently the situation in scientific work, the development of this technique to control dust was ancillary to the main thrust of a study conducted at the University of Arizona under the aegis of the National Aeronautics and Space Administration. Beginning in 1973 a number of studies were performed to determine if electrostatic charging was a factor in the levitation of dust on Mars. Since no Mars dust samples were available, tests of necessity were run on a variety of industrial and naturally occurring particulate materials. Results of this work are described in a report[14] dated August, 1977. The report contains a large amount of experimental data on dust charges and dust reduction results after applying various amounts of charged spray. In broad terms particles below 8 microns tend to be charged negatively while larger particles tend to have positive charges or to be uncharged. However, there is considerable variation among dusts and the same dust with various impurities. The physics underlying the charge phenomena and the settling mechanism is not fully developed but a government funded study is currently under way to provide a better understanding of the phenomena[15].

The variety of charge type and strength is illustrated by two bar charts taken from the report[16]. The first, Figure 24, shows that trap rock, a hard ingenous rock often found in crushed stone quarries, exhibits negative charge for all discrete particle size ranges tested up to 11 microns. Silica sand (also frequently found in stone quarries) in contrast exhibits positive as well as negative charges at some particle sizes (See Figure 25).

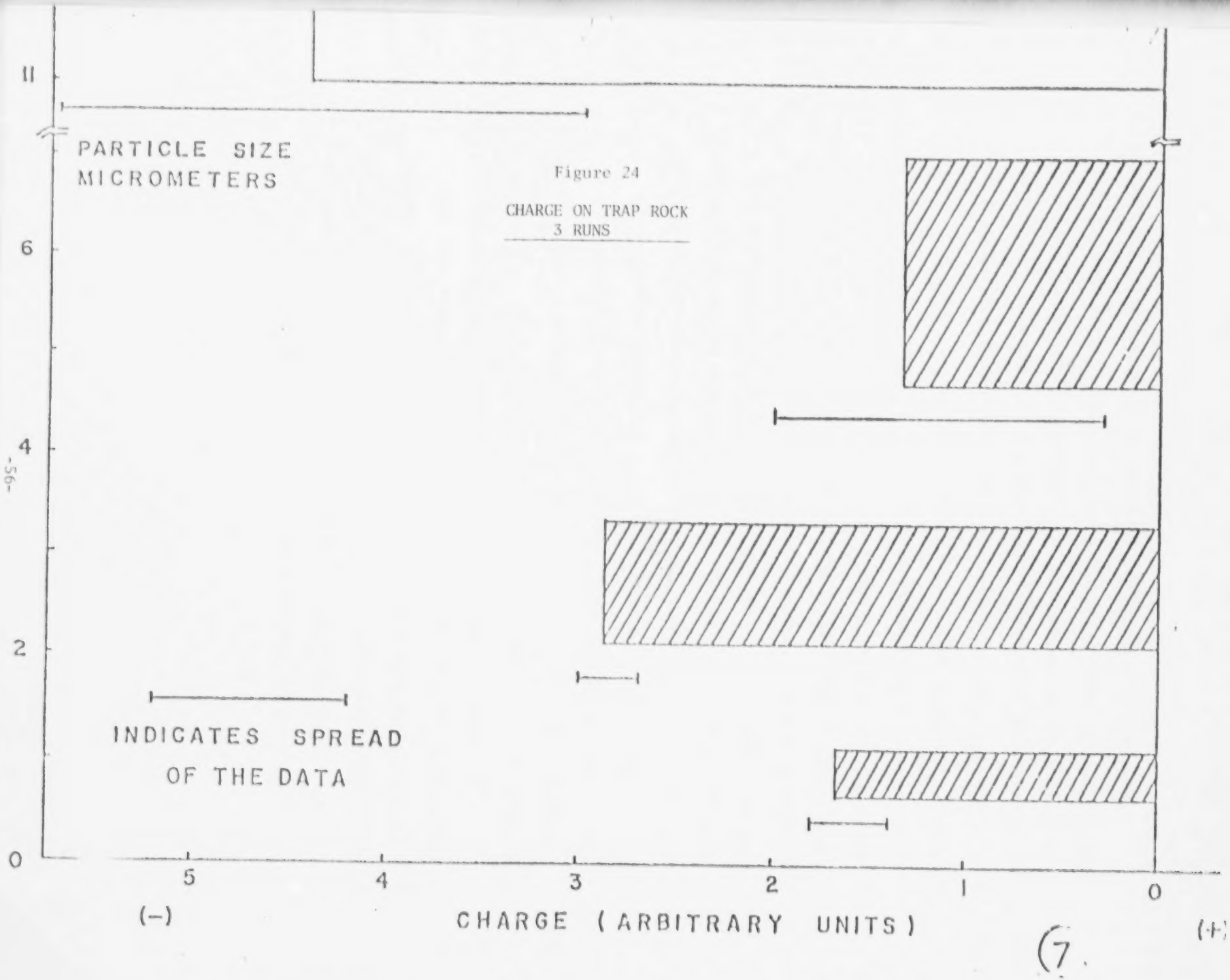


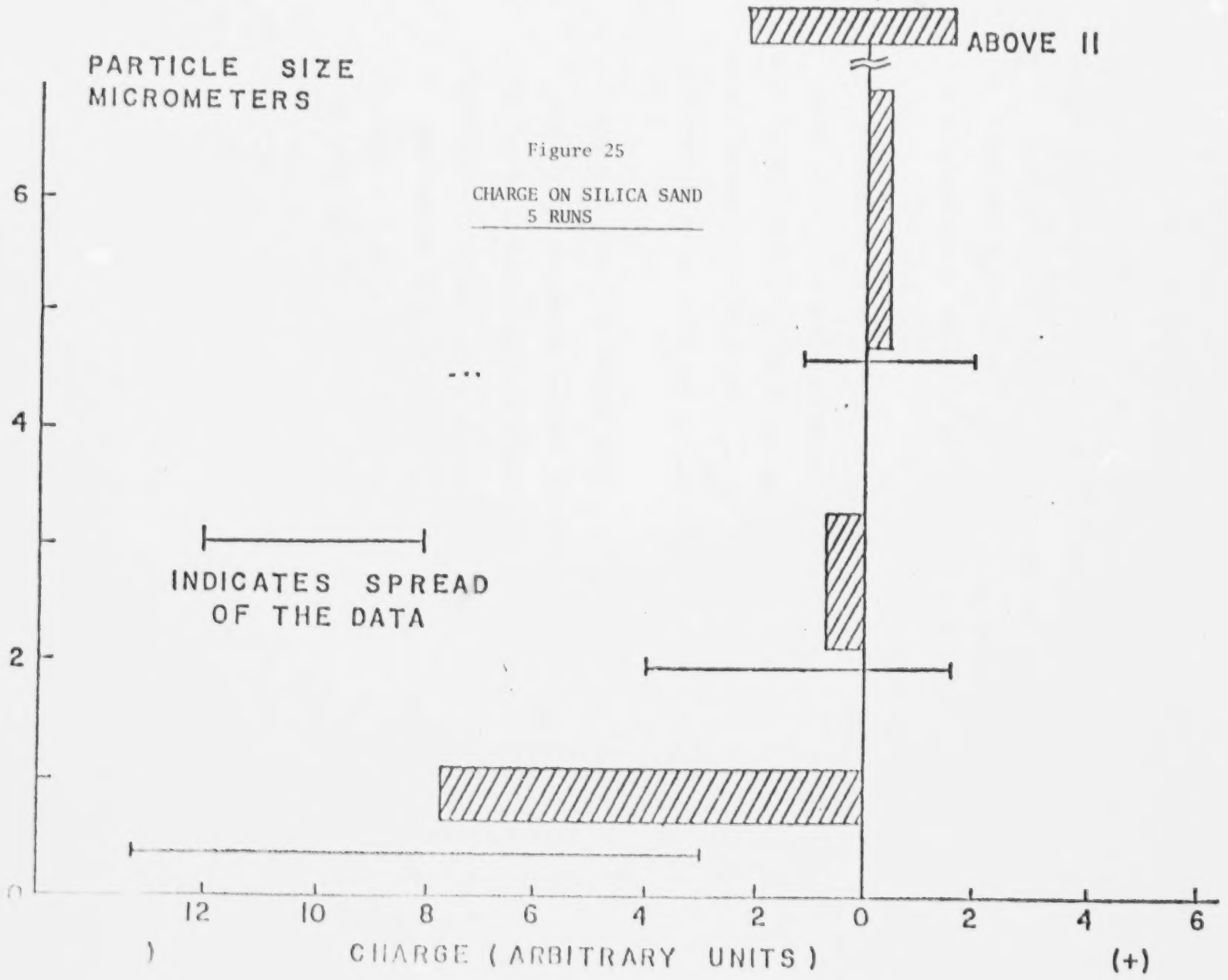
Figure 24

CHARGE ON TRAP ROCK
3 RUNS

(7.

Figure 25

CHARGE ON SILICA SAND
5 RUNS



The method employed uses small charged water particle fog. The oppositely charged fog droplets enhance contact between the particulates and the fog droplets. After contact is made, the wetted particulates agglomerate and fall rapidly. The device consists of a modified commercial electrostatic paint spray gun that uses compressed air to atomize the water droplets. The droplets can be formed uncharged, or with positive or negative charges as desired.

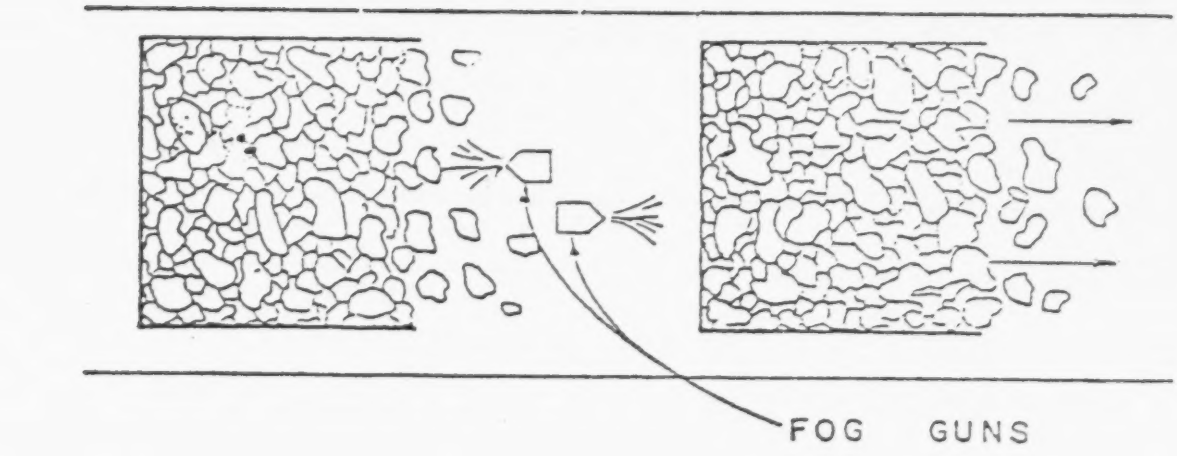
Dust tunnel studies were conducted on a variety of dust samples using various quantities of water and different charge polarities. Water flow rates were nominally 30 ml/min per gun (0.475 gallon/hour) and air flow 100 standard cubic feet per hour. All of these studies indicated reductions in dust concentration for particles smaller than 9 microns in the test dust tunnel.

Field data most closely related to crushed stone operations were gathered at a cement plant in Arizona. Samples of dust were first taken from the belt conveyor in the quarry surge building and tested in the dust tunnel for sign which indicated a preponderence of negatively charged dust. The in-plant test utilized two modified REA guns made by the Ransburg Corporation of Indiana. These two guns were mounted as shown in Figure 26.

A sampling head was then located at belt level (5', 152 cms.) and about two feet from the edge of the belt. Floor to ceiling curtains were arranged as shown in Figure 27 to prevent dust blowing in or out of the test area. Results of this in-plant test are shown in Figure 28 for particles up to nine microns. The data indicate reduction of dust level, with the most improvement coming after 30 minutes of dust loading.

Figure 26

TEST SET UP CEMENT PLANT "A"



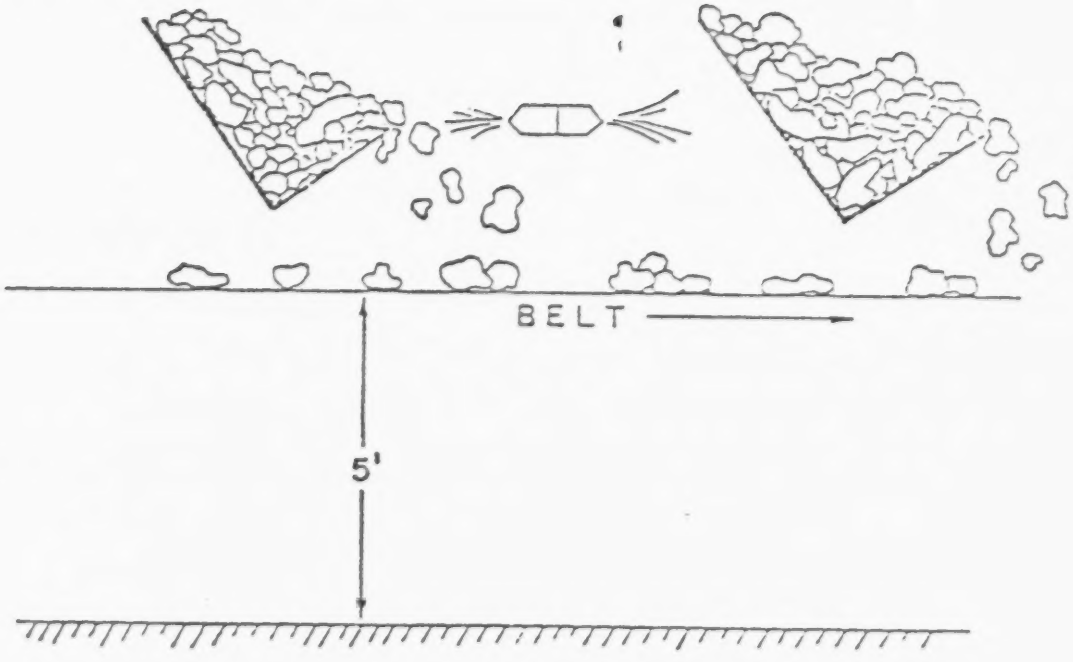


Figure 27

PLAN VIEW OF SURGE BUILDING CEMENT PLANT "A"

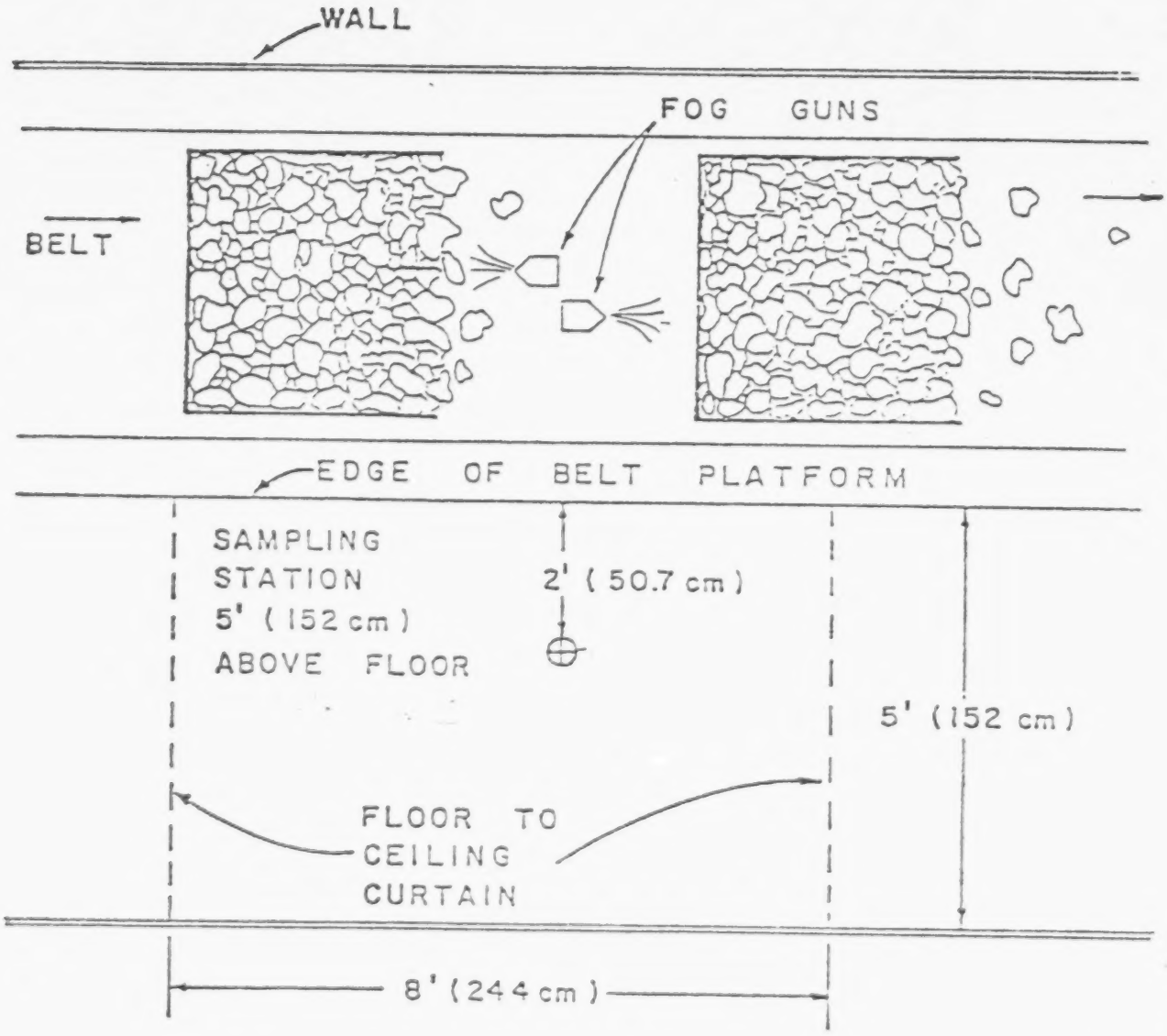
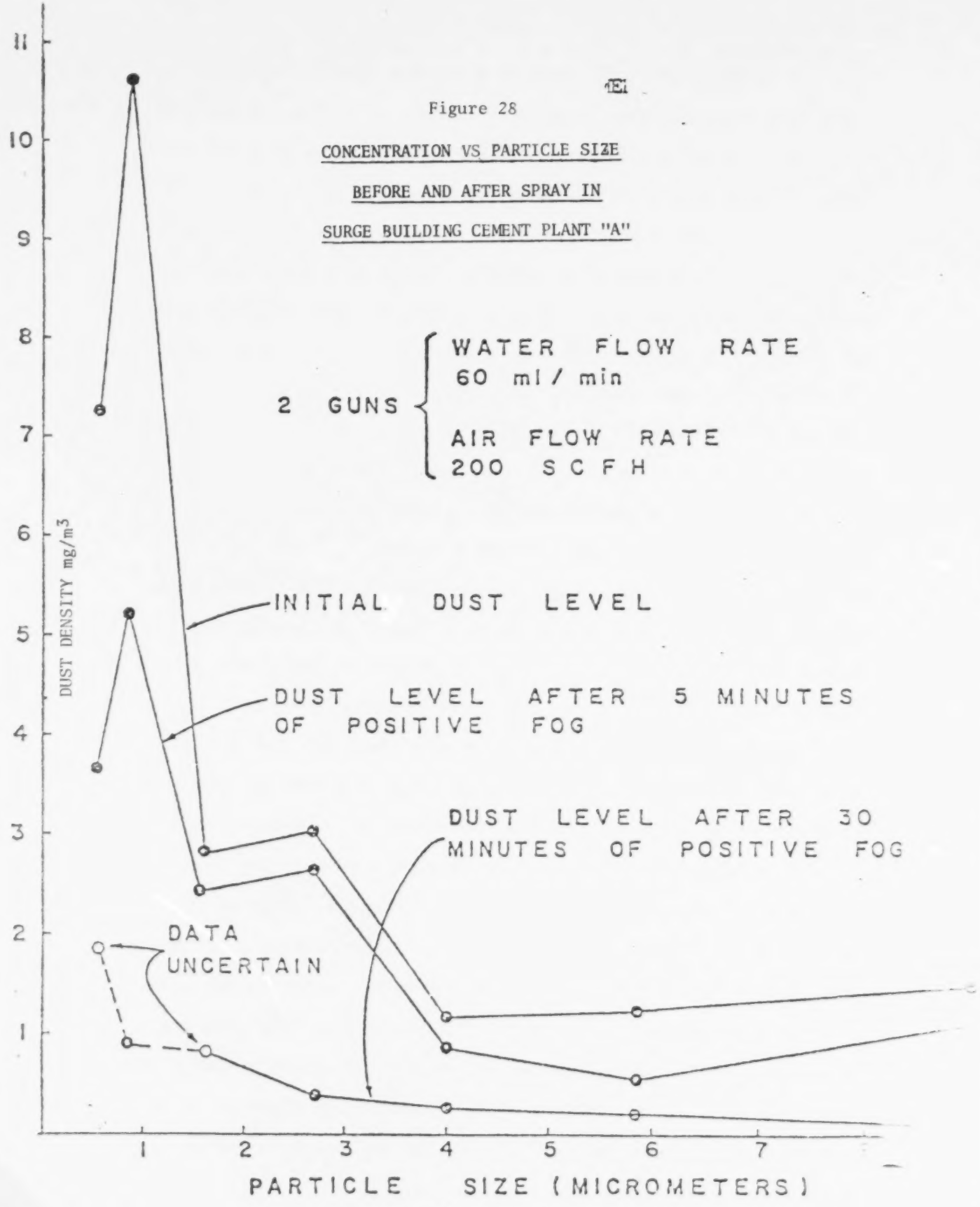


Figure 28

CONCENTRATION VS PARTICLE SIZE

BEFORE AND AFTER SPRAY IN

SURGE BUILDING CEMENT PLANT "A"



It is not possible to report on annualized costs for different crushed stone installations as was done in the case of baghouse and wet suppression systems because the system has not been deployed in the field. Individual guns consisting of a water and air atomizing head and a self-contained device to charge the particles for either polarity sell for $2,000 each from the Ransburg Corporation. One or more device must be located at each process source of dust, the area shielded from wind action, and the necessary water and air connections made. The air use of 100 SCFPH per gun is low so that even if 20 units were required (two at each of 10 emission points) plant air could readily meet the need. Water consumption for twenty units would be 9.5 gallons per hour, a small fraction of the 450 gallons per hour of water needed for a production rate of 300 tons per hour of crushed stone in a wet surpression system.

In summary, the electrostatic spray system has been applied experimentally to the control of fine dusts (less than 10 microns) with varying degrees of efficiency. There has not been operational application to crushed stone operations at this time to the author's knowledge.

Because it operates most efficiently on small particles and is essentially not helpful on particles larger than 10 microns, it cannot be characterized as a direct practical, alternative to the baghouse or wet suppression techniques extensively used in control of dust from crushed stone process operations. It should be considered for further experimentation on the smaller size dust generated by tertiary crushing which sometimes cannot be controlled by wet suppression systems because of the desire to keep the product dry. It might also be applied to dust before entering a device whose efficiency is dependent on particle mass diameter such as a cyclone or wet scrubber. Removal of the fine particles before the existing control device tends to improve its efficiency and reduce the energy necessary to effect separation by particle dynamics.

Section II

EFFECTS OF MESA CONTROL STRATEGIES ON DOWNWIND AMBIENT CONDITIONS

Introduction

The Mining and Enforcement Safety Administration (MESA)* and state agencies have promulgated and enforced worker health standards which have the potential for interaction with the enforcement of regulations promulgated pursuant to the Clean Air Act. The purpose of the work reported in this section of the report was to briefly examine the effects of control strategies for MESA on downwind ambient conditions.

Emission controls installed for worker protection under MESA or state occupational health requirements were found to ameliorate downwind ambient particulate contributions from plant operations. With certain simplifying assumptions the salutary effect on National Ambient Air Quality Standards can be calculated. However the effect of MESA and other occupational health regulations on current SIP regulations often cannot be quantitatively evaluated because SIP regulations use a different measurement criteria or are often semi-quantifiable.

It is important to note that control of process emissions for air pollution reasons, which is favored by MSHA over controlling the receptor (worker) by using protective respiration devices or a work enclosure, etc., is significantly aided by use of air pollution control devices noted in the main section of this report.

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*MESA has recently been moved from the Bureau of Mines, Department of the Interior to the Department of Labor. The changeover has been recent and the name has been changed to the Mine Safety & Health Administration.

Occupational Health Regulations

Stone quarries, also referred to as surface mining operations or simply mining in this discussion, can be regulated by more than one agency. Occupational health and safety regulations which may have an impact on air pollution control by the rock crushing industry exist at the Federal level. In addition some states also have occupational health regulations that pertain to this industry. Since there is considerable variation in state activity we will generally use Oregon and Pennsylvania as illustrative examples.

MESA. The federal Mining Enforcement and Safety Administration (MESA), an agency of the U.S. Department of Interior, was created in 1973 to take over from the Bureau of Mines the authority to develop and enforce health and safety standards under the Federal Coal Mine Health and Safety Act and the Federal Metallic and Nonmetallic Mine Safety Act (FM&NMSA), 30 U.S.C. §721 et seq.

The FM&NMSA, which applies essentially to all mining operations, both deep and surface, grants MESA authority to enter and inspect all subject mines. The Act empowers MESA to promulgate two types of health and safety standards: voluntary and mandatory. Voluntary standards may be set to protect life, promote health and safety, and prevent accidents. Voluntary standards are similar to guidelines: operators may not be penalized for violating them. MESA may also set mandatory standards to regulate practices reasonably expected to cause death or serious physical harm. Violations of mandatory standards may lead to imposition of the penalties specified in the Act.

The states may be delegated inspection and enforcement authority

under the FM&NMSA if they submit a plan that is approved by the Department of Interior. If the state plan is approved, MESA essentially turns over the enforcement of the standards to the state. To date six states have been delegated inspection and enforcement authority. Oregon and Pennsylvania are among those that have not been delegated such authority. State mine regulatory laws that are not in conflict with FM&NMSA, or that regulate mines more strictly than the Act, are not superseded by it, so Pennsylvania's law and the FM&NMSA are both enforced in Pennsylvania. This is also true in Oregon, except that an accomodation has been reached between the two enforcement agencies so that little overlap occurs in field enforcement.

OSHA. The Occupational Safety and Health Act of 1970, 29 U.S.C. §65 et seq., created the federal Occupational Safety and Health Administration and gave it authority to enter and inspect all business establishments in the United States and its territories. OSHA has authority to set and enforce standards, issue citations, assess fines, and petition federal courts to close down establishments where employees are threatened by imminent hazards.

OSHA currently exercises no jurisdiction over mining enterprises, except for practices occurring in buildings outside the mine or pit (crushing, screening, and conveying are deemed not "outside the pit"). While neither the OSHA Act nor the FM&NMSA preclude OSHA from setting and enforcing regulations pertaining to mines, any such action would be a mere duplication of MESA's efforts. OSHA has issued no safety or health standards for mines to date, nor does it presently enter and inspect mines, despite its legal authority to do both.

EPA - SIP. The federal Environmental Protection Agency is charged with enforcing the federal Clean Air Act (CAA), 42 U.S.C. §1857 et seq.

The CAA is based on a regulatory concept involving ambient air quality and emissions limitations; it does not give EPA authority to set exposure levels of air pollutants for workers. EPA, in any case, only retains primary enforcement authority over hazardous emissions (including asbestos) and emissions from certain new sources (not yet including any quarrying operations). Enforcement of emission limitations for non-hazardous pollutants from existing sources can be delegated to the states after approval of their state implementation plans. EPA can enforce state SIP's if state enforcement is inadequate.

State Health Agencies. Some states also have state industrial health organizations that regulate and inspect mining operations. For example, when the Pennsylvania Department of Environmental Resources (DER) was created in 1970, among the powers it was delegated was the power to set and enforce health and safety regulations for mines, previously invested in the Department of Labor and Industry. DER's authority over mines is derived from the Pennsylvania Surface Mining Conservation and Reclamation Act, 52 P.S. §1396.1 et seq. The inspection and enforcement is handled by the Bureau of Occupational Health.

The Surface Mining Act gives DER exclusive authority to enter and inspect any surface mine in the state. The Act also empowers DER to issue and enforce such regulations as are necessary to protect mine workers and public health and safety. This Act does not distinguish between voluntary and mandatory standards; all standards issued by DER are mandatory and enforceable. The state regulations and those of MESA are essentially identical insofar as worker exposure is concerned.

Oregon's situation in respect to state involvement with occupational health at surface mining installations is similar in theory, but not in

practice. There is regulatory overlap between MESA and the Accident Prevention Division (APD) of the Worker's Compensation Department (formerly Workman's Compensation Board). The APD and MESA, however, have an arrangement under which MESA has primary inspection responsibility. APD only inspects if they happen to be on the site for another purpose, and have determined that there has not been a recent inspection. Copies of inspection reports are exchanged between APD and MESA.

Comparing Pennsylvania, the leading stone producing state, and Oregon, approximately the thirteenth in terms of production, insofar as regulatory bodies concerned with air pollution at stone crushing operations we see the following:

Enforcement Agencies for Fugitive Dust

From Stone Crushing Operations

Pennsylvania	Oregon
Pennsylvania Department of Environmental Resources (Bureau of Air Quality and Noise Control) enforces EPA approved SIP.	Oregon Department of Environmental Quality enforces EPA approved SIP.
Pennsylvania Department of Environmental Resources (Bureau of Occupational Health) inspects surface mines and enforces worker standards.	Oregon APD of the Worker's Compensation Department inspects and enforces worker standards in a variety of industries including surface mines.
MESA inspects and enforces worker standards in surface mines.	Same.

Thus there is an overlap in both Pennsylvania and Oregon between state and MESA inspections and enforcement authority.

Worker Exposure Regulations. The MESA standards that apply to worker related air contaminants are mandatory in nature. They are based on the threshold limit values (TLV's) for nuisance dusts and dusts containing quartz and asbestos recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). The following common TLV's are therefore applicable to the rock crushing industry:

Substance	TLV
Nuisance Dust	$10 mg/m^3$
Quartz	$(10 mg/m^3) \div (\%$ Respirable Quartz + 2)
Asbestos	5 fibers/ml. (fibers greater than 5μ in length

Under these regulations, no employee in a rock crushing plant is to be exposed to an averaged 8 hour working day dust concentration greater than the TLV. For 5% Quartz content, the above TLV formula reduces to:

$$10 mg/m^3 \div (5\% + 2) = 1.43 mg/m^3 \text{ or } 1430 \mu g/m^3$$

SIP Regulations on Fugitive Dust. The SIP requirements for non stack emitted dust (fugitive dust) in states vary to the extreme. Several examples will illustrate this point. The reader is cautioned that the following examples note highlights of the regulations, and are not to be considered as exhaustive or definitive legal treatments.

Pennsylvania permits no fugitive dust unless the operation falls in either of eight categories (construction, agriculture, etc.) or is classified by PennDER as an "insignificant" source. Stone crushing is not inlcuded in the eight categories and each operation is judged on its own as to whether or not it is an insignificant source. If significant no fugitive emissions are permitted, while if insignificant, measurements are made downwind at the property line using a Konimeter, a device which is intended to provide particle count and size information. The DER regulations specify no more than 150 particles per cubic centimeter downwind air above background at the property line. These instruments have been found to be unacceptable for this purpose by this contractor and the state, and their use has been abandoned.

Oregon does not have a performance regulation on fugitive emission, but requires the "installation of hoods, fans, and fabric filters to enclose and vent the handling of dusty materials" (OAR 21-060, 20). These regulations apply however only if a nuisance condition exists or if any other regulation is violated. The existence of a nuisance condition is determined by such factors as population density, duration of the activity and others (OAR 21-050 (2)). This regulatory arrangement leads to the not uncommon problem posed by having objective criteria which cannot be quantitatively applied.

In addition, existing sources outside Special Control areas are subject to a 40% opacity limitation (Ringelmann 2). All new sources and existing sources outside the Special Control areas are subject to a 20% opacity limitation (Ringelmann 1) (OAR 21-015).

Arizona fugitive dust regulations require the use of "reasonable precautions" to prevent particulates from becoming airborne from certain activities. For crushing, screening, handling, or conveying of materials, such reasonable precautions are defined to include (but are not limited to) spray bars, wetting agents, and hoods (Arizona Rules and Regulations R9-3-302 (D)).

In Texas, in the Standard Metropolitan Statistical Areas (SMSAs) in which federal ambient air quality standards for particulates are exceeded, fine material may not be handled, transported, or stored unless stockpiles and other surfaces from which airborn dust may arise are coated with water, chemicals, or other suitable materials; hoods, fans, and filters are used to collect dusty materials; and open vehicles are covered and materials wetted (Texas Regulation I, Rule 104). Portable rock crushers on site less than six months and engaged in public works projects are exempt from visible emissions and process rate standards (Rules 103 and 105) as long as they are located at least one mile outside the nearest town limits, occupied facility, or recreational area; equipped with cyclones, wet scrubbers, or water sprays (or equivalent) at transfer points; do not create a nuisance; and not in Dallas or Harris counties (Regulation I, Rule 106).

In Utah, all sources emitting over 100 tons of particulates annually (uncontrolled) must achieve 85% control. No methods are specified (Utah State Division of Health Code of Air Conservation Regulations §2.3.1).

Relationship of Control for Workers to SIP Control

An interesting topic concerns the extent to which control of fugitive dust emissions from stone crushing operations to satisfy MESA type requirements

aids in the attainment of SIP standards. This is a very difficult subject. MESA requirements are based on a dosage concept that involves a pollution field and a receptor (the worker). The TLV's are based on an eight hour working day exposure. The method of test for worker dust exposure is to attach on the upper torso clothing of a worker the input section of a calibrated vacuum pump so that it provides an inspired volume flow rate similar to a normal adult worker. The worker shuts the device off during work breaks so that the air inspired by the device is similar to that inhaled by a worker acting on the job over an eight hour period. Dust is separated into respirable and non respirable fractions by a small cyclone in the device and the respirable portion caught on a filter. Gravimetric determination of the filter catch is made and the weight of dust divided by the volume of air passed through the device over an eight hour period. The result is an eight hour average exposure which is then compared to the pertinent TLV. Anything that will reduce the worker's exposure such as work rotation, dust free booths, personal protection (respirators) can be used. Note that the pollution field has not been reduced, only the workers exposure to that field has been lessened. MESA prefers engineering controls at the source (emission controls) or at the receptor (by enclosing the employee in a dust-free booth). Source emission controls are therefore the only ones that could possibly be analyzed as to the degree to which MESA standards attainment helps SIP attainment. Because, as was shown earlier, the SIP standards for fugitive dust vary significantly among the states and are usually not given in concentration terms it is extremely difficult to make such analysis.

A statement of the question in different terms helps the analysis: To what extent does the attainment of MESA standards by emission control

strategies on otherwise non MESA compliance operations improve the National Air Quality STandards (NAAQS) in the vicinity of the operation? NAAQS for particulates are:

Annual daily geometric mean:	Primary	$75\mu g/m^3$
	Secondary	$60\mu g/m^3$
Maximum 24 hour average:	Primary	$260\mu g/m^3$
	Secondary	$150\mu g/m^3$

The restated question may be addressed more effectively than the former question, and if certain simplifying assumptions are made, a mathematical expression relating such variables as distance to the property line, wind speed, etc. can be formulated. Appendix A of this report includes an example of how such an analysis can be made, given with underlying assumptions.

The plant with the particular geometry described in Appendix A has reduced its contribution to the 24 hour average ambient at the property line by nearly 53% (from 286.1μgm^{-3} to 135.1μgm^{-3}) by meeting MESA standards for the working environment.* Differing backgrounds, geometries, work shifts, and before-control worker ambient levels would yield differing results in accordance with equations 1, 2 and 3 of the Appendix, and the correction from 8 hour TLV to a 24 hour ambient. Thus the enforcement of applicable emission regulations and worker exposure provisions are considered mutually supportive and complementary to the other program objectives.

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*For a given r and stability class. See the Appendix for the range of possibilities.

APPENDIX A

Example Analysis of Effect of MESA on NAAQS

The question addressed is, what extent will pollution controls intended to meet one standard (i.e. MESA standards) contribute toward meeting another standard (i.e. National Ambient Air Quality Standards)? The answer depends upon the extent to which the pollutant being regulated contributes to the pollutant governed by the second standard. In this discussion we will assume that the second pollutant is identical to the first. Also, we will assume inert pollutants (e.g. 5% quartz stone dust) with no fall out, an ambient particulate background concentration of 100 $\mu g/m^3$, and atmospheric conditions such that the dilution downstream from the source is governed by the Gaussian plume relationship.

It is reasonable to use the Gaussian model in this situation since we are not concerned with particle fallout, rather only those particles that do not fall out within the plant property line. In terms of MESA Standards we are concerned with respirable size particles, i.e. 0.1 μm to 10 μm diameter, and their control. These particles remain airborne for sufficient time periods to consider their dispersion according to the Gaussian plume model.

As a starting point, we define the following pollution concentrations in micrograms per cubic meter:

χ_R - pollutant regulated by the first standard;

χ_2 - pollutant governed by the second standard;

χ_{Rb}, χ_{2b} - concentrations of χ_R and χ_2 before controls are instituted;

χ_{Ra} χ_{2a} - concentrations of χ_R and χ_2 after controls are instituted.

These relations follow by definition also:

$$\Delta\chi_R = \chi_{Rb} - \chi_{Ra} ;$$

$$\Delta\chi_2 = \chi_{2b} - \chi_{2a} .$$

These represent the controlled pollutant concentrations.

Let us now examine how ΔX_R and ΔX_2 are related as a function of distance d downwind of the pollution source area. To do so we can envision a Gaussian plume dispersion model extending downwind of the plant site area A_s as sketched in Figure 1-A. The pollution concentration at ground level averaged over about one hour is sketched at L_1 and L_2 showing the pollution spread out and decreased in concentration. In a later example, L_2 will be taken to be the boundary of the plant property at which NAAQS must be met and L_1 is the critical point with regard to MESA standards.

The ground level concentration is a maximum at the plume centerline and decreases from L_1 to L_2 according to the relation

$$\chi = \frac{Q^1}{\pi\sigma y\sigma z\mu}$$

where

$\chi(\mu gm^{-3})$ is the pollutant concentration,

$Q(\mu gs^{-1})$ is the source strength,

$\sigma y\sigma z(m^2)$ is the product of Gaussian plume dispersion parameters and,

$\mu(ms^{-1})$ is wind speed.

The above expression is for a continuous point source with ground level release.

From the above relationship we see that the ratio of concentraion at L_2 to that at L_1 is r where;

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[1] Turner, D.B., 1969: Workbook of Atmospheric Dispersion Estimates. Public Health Service, HEW.

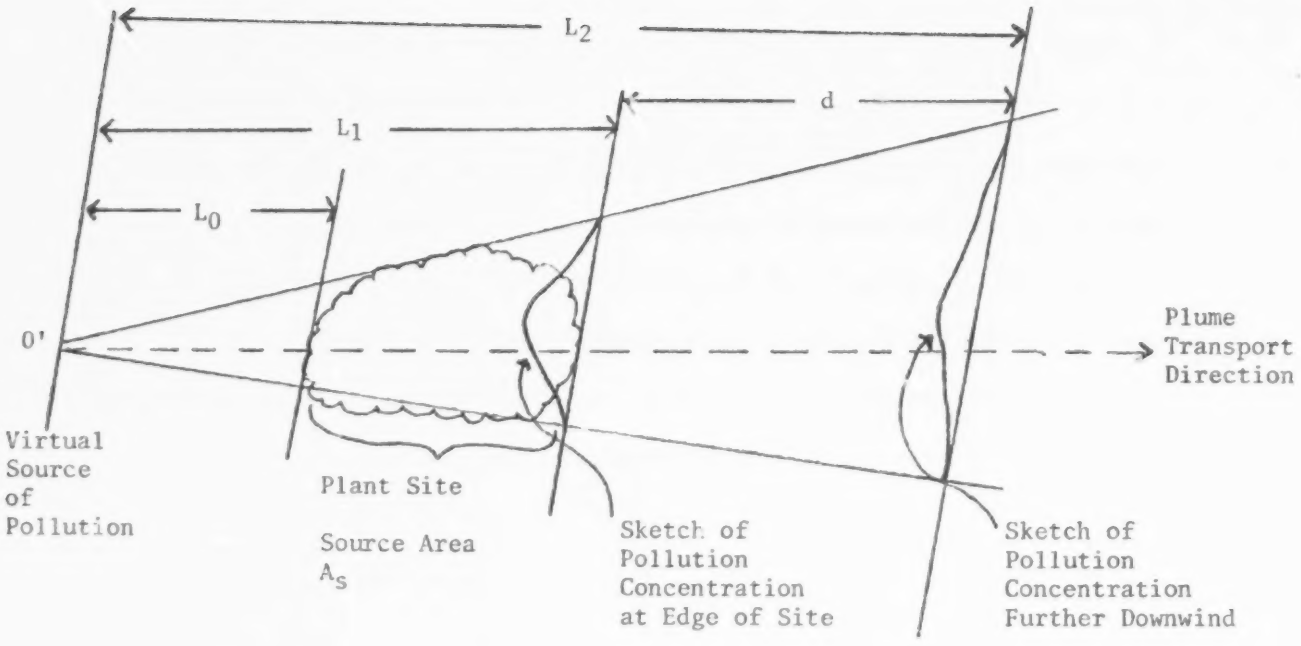

Figure 1-A: Sketch of the Geometric Relation Between the Virtual Source Point O', the Source Area A_s and Average Pollution Concentration at L_1 and L_2

$$r = \frac{X(L_2)}{X(L_1)} = \frac{[\sigma y \sigma z](L_1)}{[\sigma y \sigma z](L_2)} \qquad \text{(Equation 1)}$$

The ratio of Gaussian parameter products can be estimated for various values of L_1 and L_2 from the following table derived from the graph of Figure 2-A for various stability classes. This table presents the values of the Gaussian parameter products $\sigma_y\sigma_z$ for various stability categories at the corresponding downwind distance.

Gaussian Parameter Products, $\sigma_y\sigma_z$ (m^2) for Various Stability Classes And Downwind Distance L(km)

Downwind Distance, L(km)	.1	.5	1	5	10
Class B	120	4,500	16,000	400,000	off graph
Class C	96	1,800	6,400	115,000	400,000
Class D	40	660	2,100	26,500	74,000
Class E	25	360	1,100	12,000	32,000

Applying the distance reduction to ΔX_2 which would be at L_2 and ΔX_R at L_1 shows that

- $X_{2b}(L_2) = rX_{Rb}(L_1)$ (Equation 2)
- $X_{2a}(L_2) = rX_{Ra}(L_1)$ (Equation 3)

These relations show how pollution concentrations due to control measures initiated at point L_1 relative to pertinent regulations translate to pollutant concentration at point L_2 relative to another standard. Thus under the simplifying assumptions made, any reduction in source strength from the various fugitive sources will have the effect of a corresponding decrease in

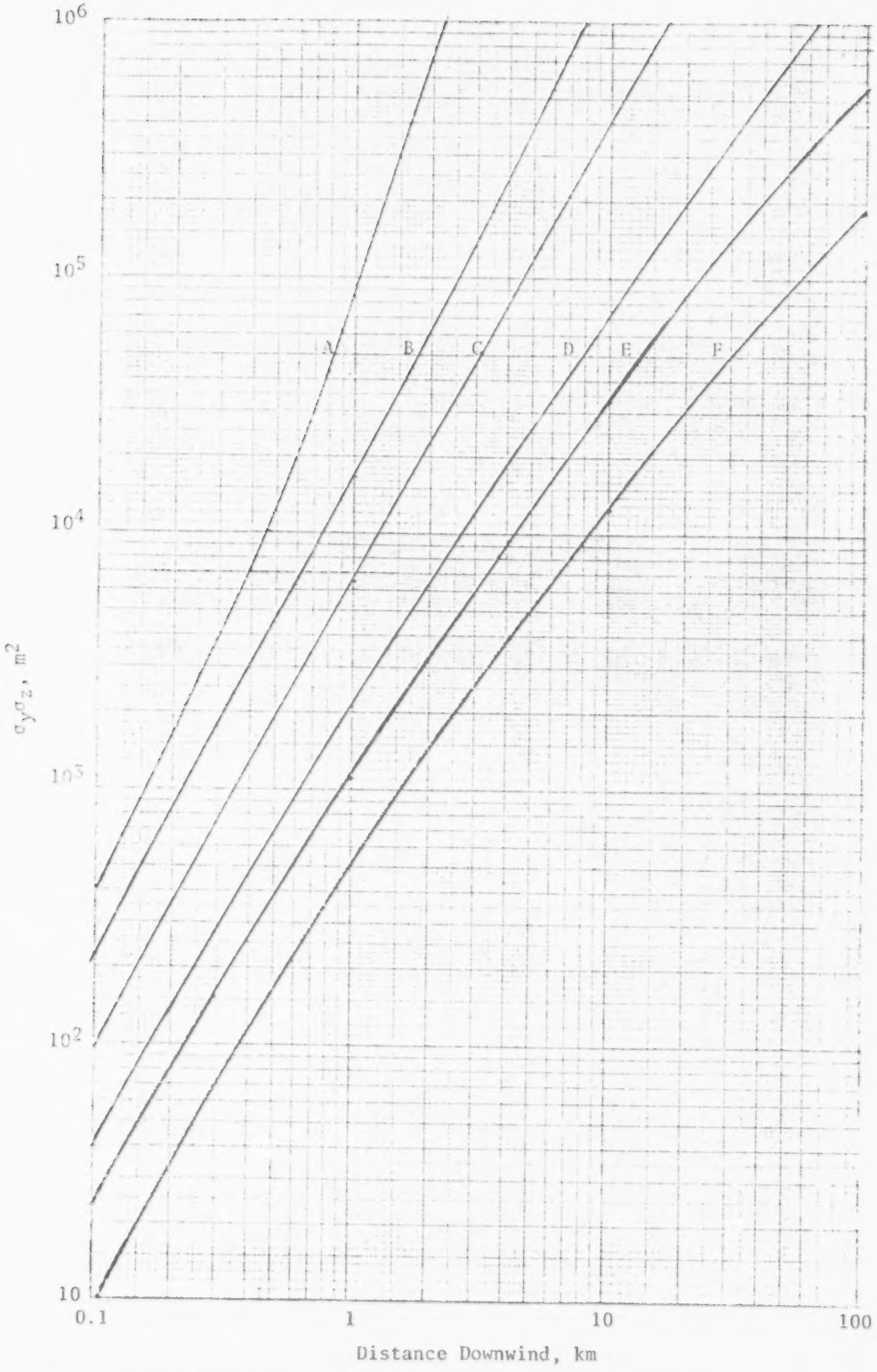

Figure 2-A:The Product of $\sigma_y\sigma_z$ as a Function of Downwind Distance From the Source. (A Represents Unstable Conditions and F very stable.)

Source: Turner, D.B., Workbook of Atmospheric Dispersion Estimates, U.S. EPA.

their contributions to the downwind ambient. How this would work in the case of a stone crushing operation can be seen in the following example of a stone crushing operation processing 5% quartz stone with a plant area ambient concentration of dust at 7150 μgm^{-3}. The TLV criteria for 5% quartz dust established by MESA is 1430μgm^{-3} as noted earlier in this section of the report. To meet this standard an 80% reduction of quartz bearing dust is accomplished at the plant site by employing emission controls. For this operating site with L_1=1km, what is the impact of these operating site controls at the plant boundary 4 km beyond the operating area, i.e. L_2=5 km?

Notice that the particulate concentration measured in the plant area includes the background concentration of 100μgm^{-3}. To determine only the plant's contribution to the ambient concentration at the plant boundary, the background concentration should be subtracted from the plant area concentrations before applying equations 2 and 3. Thus the plant area concentration attributed to plant operations prior to control, χ_{Rb}, is 7050 μgm^{-3} and after control, χ_{Ra}, is 1330 $\mu g/m^3$.

The following calculations exemplify the use of equations 2 and 3 in determining the effect of controls initiated within the plant area on the ambient concentration at the property line. Calculations are based on atmospheric stability class D.

From Figure 2-A and equation 1 we find that:

$$r = \frac{\sigma_y \sigma_z \ (L_1)}{\sigma_y \sigma_z \ (L_2)} = \frac{2100 m^2}{26500 m^2} = 0.0792$$

During an eight hour work day

$$\chi_{2b} \ (L_2) = r \ (\chi_{Rb}) = 0.0792 \ (7050) = 558.4 \ \mu g/m^3$$

$$\chi_{2a} \ (L_2) = r \ (\chi_{Ra}) = 0.0792 \ (1330) = 105.3 \ \mu g/m^3$$

$$\Delta\chi_2 \ (L_2) = 453.1 \ \mu g/m^3$$

The contribution of the plant to the ambient particulate concentration at the plant boundary before and after control is thus 558.4 μgm^{-3} and 105.3 μgm^{-3}, respectively. There is approximately an 80% reduction in the plant's contribution to the ambient. Since we assumed a background concentration of 100 μgm^{-3}, the actual ambient concentration of particulates 5 km downwind would be 658.4 μgm^{-3} before control and 205.3 μgm^{-3} after controls were initiated at the plant. These values must then be converted to 24 hour average concentrations to be compared to the NAAQS for particulates of 260 μgm^{-3}.

During non-working hours the ambient concentration is 100 μgm^{-3}. Therefore, the 24 hour average concentration is

$$\overline{\chi}^{24\ hr}_{2b}\ (L_2) = 1/3\ (658.4) + 2/3\ (100) = 286.1\ \mu g/m^3$$

and

$$\overline{\chi}^{24\ hr}_{2a}\ (L_2) = 1/3\ (205.3) + 2/3\ (100) = 135.1\ \mu g/m^3$$

Thus the plant with this particular geometry (the assumed L_1 and L_2) for atmospheric stability class D has reduced its contribution to the 24 hour average ambient at the property line by nearly 53% by meeting MESA standards for the working environment. In doing so, the ambient concentration was reduced below the NAAQS for particulates of 260 μgm^{-3}. Differing backgrounds, atmospheric stability classes, geometries, shifts, and before control worker ambient levels would yield differing results in accordance with equations 1, 2, and 3 and the correction from 8 hour TLV to a 24 hour ambient.

Table 1-A shows the effect of the choice of stability class on the 24 hour average ambient concentration. The values were developed in the same

manner as the preceding calculations, only the value of r was changed in accordance with the Gaussian parameter products from Figure 2-A.

Table 1-A

Stability Class	B	C	D	E
r	.0425	.0557	.0792	.0917
$\overline{\chi}^{24\ hr}_{2b}(L_2)$ ($\mu g/m^3$)	199.9	230.9	286.1	315.8
$\overline{\chi}^{24\ hr}_{2a}(L_2)$ ($\mu g/m^3$)	118.8	124.7	135.1	140.7
% reduction of ambient 24 hr. avg. concentration	40.57	45.99	52.78	55.45

This table shows that the 24 hours average concentration at the property line decreases going from Class E to B as the atmosphere becomes more unstable. Obviously, this is because the diffusion capability of the atmosphere increases in proportion to the atmospheric turbulence. Granted, the background concentration would also vary with atmospheric stability, but this effect is beyond the scope of our analysis. Additionally, the percent reduction of the ambient 24 hour average concentration decreases as the atmosphere becomes more unstable. This is because the contribution to the ambient from the plant during the 8 hour working day decreased with the ratio of the Gaussian parameter products while the background concentration was assumed constant for the 24 hour period. Thus the effect of the controls initiated at the plant is reduced in terms of the 24 hour average concentration.

Notice that for stability classes B and C the 24 hour average concentration at the property line is already within the limit of the NAAQS before

controls were initiated at the plant. Thus, pollutant control is not necessary to meet these standards if the property line is 5km from the source. Stability Class D, neutral stability, is more or less the worst case situation in terms of downwind centerline concentration during an 8 hour work day. By definition stability class E does not occur during the day. This shows that by controlling particulate concentrations at the plant by 80% in order to meet MESA standards a corresponding 53% reduction in the ambient concentration at the property line will result which also meets the NAAQS. As previously stated, different background concentrations, plant geometries, shifts and before control worker ambient levels will yield different numerical results.

Controls installed for air pollution control reasons also have the salutary effect of reducing worker ambient levels. Thus MESA (now MSHA) and EPA regulations have mutually desirable effects.

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